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and

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FOR HOME - STUDY



VOLUME ONE

Fundamentals of Radio and Electronics



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PRACTICAL RADIO AND ELECTRONICS COURSE

VOLUME ONE
Fundamentals of Radio and Electronics

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A Welcome and Introduction to You

YOUR decision to study and advance in Electronics and Radio was well made. After the last War, great progress was made in the automobile field. Beginning with commercial radio broadcasting in 1923, stupendous advances have been made in radio communications, television, and facsimile. This War has shown thousands of new uses for radio. Applications, circuits, accomplishments, not even imagined a few years ago, are now being used to speed victory for the United Nations.

You, as a progressive mechanically inclined person, have realized that new peace-time opportunities will lie in the expanding field of Electronics. This field no longer embraces only the tremendous functions of wireless code and 'phone communications, broadcasting, television, long distance telephone, airplane beacon stations, news picture transmission, and the associated millions of jobs of building, maintaining, operating, and repairing billions of dollars worth of equipment, but unforeseen and revolutionary new uses for Electronics are found every day to be applied to civilian life immediately after the War. Hundreds of good-will advertisements of the largest corporations in America, appearing in all leading magazines, have told you a story of Electronics accomplishments and the true possibilities after the War. And you are planning to be in the midst of this opportunity.

What is the science of Electronics? Application of vacuum tubes in special circuits to perform useful functions falls in the field of Electronics. All radio equipment, airplane locators, color matching, electronic cooking, telephone repeaters, welding equipment, absolute altimeters, radar for gun control are all dependent on Electronic vacuum tubes. Engineers have made the bold statement that Electronic equipment can be made to perform all the functions of the human senses — sight, smell, touch, hearing, and taste. And what is more, Electronics can perform almost any task without error, tirelessly, and at unbelievably low cost.

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This complete home-study *Practical Radio and Electronics Course*, you are now reading, has been prepared to help you get into this expanding field. This three volume course has been purchased by you at a saving. You have paid but a fraction usually charged for any similar home-study course sold in individual lessons. When you finish studying this course under the helpful directions and guidance instructions included, you will be ready to accept work as a radio and electronic equipment serviceman, laboratory assistant, factory inspector, or any other similar job paying excellent wages.

You must understand how to study the course. On each page, you will find two columns. In the wide column is the text material just like a book used at school. In the narrow column you will find the instructor's comments, helpful suggestions, additional pictures and remarks to simplify the difficult parts. You study by reading the text in the wider column. The comments in the narrow columns are read as they are found adjacent to the other reading matter.

The review questions and problems must be carefully answered in writing. A notebook should be kept with all the answers. Occasionally you will find hints and suggestions to help you with the problems. In many cases, the answers are stated so that you can check the corrections of your own results.

Assign certain periods of each day to your radio and electronics studies. Tackle this study in a happy spirit, always thinking of the accomplishments that lie ahead. Progress along as quickly as you are able, but do not pass any section until you have mastered the contents. As an additional aid, you may purchase a complete book of answers to the review questions and problems. This booklet is priced at 25c, postpaid.

We know you will succeed in learning the interesting and essential facts about practical radio and applied electronics. Good luck in your studies and work.

M. N. Beitman

November, 1943.
Chicago, Illinois.

LESSON 1

What Makes Up a Radio Receiver

THE INSIDE OF A RADIO. You are going to begin your study of radio in a *practical* way. The small radio set you probably have in your home or can obtain from a friend will be your first laboratory. You will only look at the parts and examine the connections. You will not make any changes and will be careful in your work. The radio set will remain in fine shape and you will gather a world of knowledge about the parts used in all types of radio equipment.

The radio you select for these visual observations first of all must be tested. You already know how to *rough-test* a radio. Simply make certain that the required electrical connection for power is made. In electric sets this means that the plug must be connected. If used, the antenna wire also must be connected. Then tune in one or two stations to check if the radio set is operating properly.



Figure 1. Any small, home radio receiver can be used for the simple experiments described. Complete instructions are given for the work to be performed.

After this test, remove the power plug from the receptacle and disconnect the antenna wire. Begin at once to practice the correct way for doing every radio task. An expert radio man plans his every step and performs the task first in his mind. Then the expert follows through with the actual operation. For example, plan in your mind how you will remove the plug. Make certain you will not bump something with your elbow, and pull on the plug and not the wire.

REMOVING THE KNOBS. Now examine the front of the radio you are using. It probably has several knobs, for selecting the desired stations, for controlling the volume, and for other purposes. These knobs usually must be removed to take the radio chassis (the actual radio) out of the cabinet. Most knobs fit over the shafts of the parts of the radio, and are held in place by small set screws. Look at the side of a knob instead of the front. Rotate this knob. Do you see a small opening and, inside of this opening, the head of a tiny screw? The knob may be removed by first loosening this set

In this column you will find additional explanations, hints, suggestions for study, and other remarks usually expressed by the instructor in a class room. You are to read the main text in the wide column first. The *explanation* notes in the narrow column should be noticed as the main text along-side is read.

The choice of a radio for these safe *examination* experiments is not critical. A small table radio is easier to handle. You must be careful in handling the receiver; by following the directions exactly, you will make certain that the set will operate properly when you work is completed.

Will your radio operate without any antenna wire? Try it out. What do you think the antenna wire does? You are right, if you understand that it picks up the radio signals.

REMOVING THE CHASSIS

Since radio repair work must be performed inside the radio chassis, special supports are available which will hold the chassis in a suitable position to permit the serviceman to reach underneath to make the required measurements and tests.

You are always safe in touching *insulating* parts such as glass of the tubes, wax cardboard containers. Any single metal connection may be touched with an insulated screw driver provided the metal of the blade does not touch other parts at the same time.

screw. After this the knob can be taken right off. You know, of course, that standard screws are loosened by turning a screw driver to the left, i.e. counter-clockwise, in the opposite direction in which clock hands turn. If you do not have a small screw driver to fit the small openings in the knobs, a small knife or a nail file may do the trick. Later when you replace the knobs, tighten the set screws just enough to make the knobs turn the needed controls and not slip on the shafts.

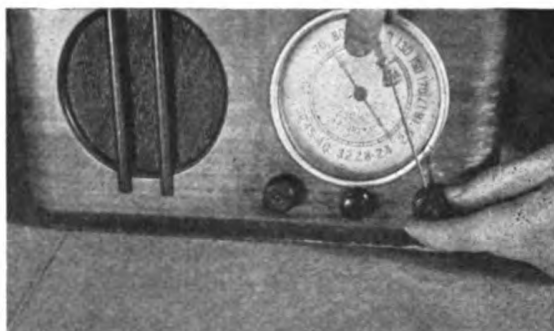
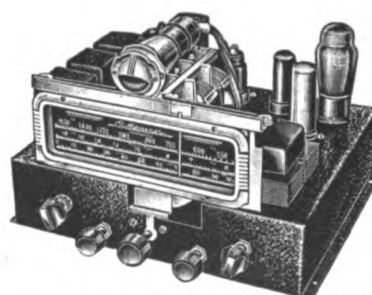


Figure 2. Most radio control knobs may be removed with the aid of a small screwdriver.

You may find that the knobs on your radio set do not have set screws. If this is the case, the knobs may be removed by simply pulling on them. After pulling these knobs off, notice how they fit on the shafts and plan to replace them in exactly the same way.

REMOVING THE CHASSIS. Now you must examine the entire cabinet, especially the back and bottom, to see how the radio metal-chassis is held in place. Probably several bolts hold the chassis in place and the bolts have their heads coming out at the bottom of the cabinet. If this is so, remove these bolts. The back of the cabinet may have a panel which also must be removed. When all required bolts have been taken out, the chassis will slide out easily from the cabinet. Be careful of the dial assembly. Notice how the equipment fitted together, so that you can assemble things back in place easily and quickly.



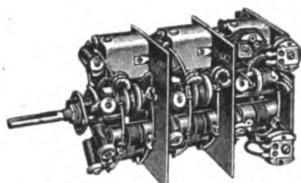
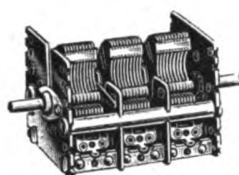
Courtesy Meissner Mfg. Co.

Figure 3. Your radio receiver may look somewhat like the chassis illustrated.

Since the radio is not connected, you are safe in placing your hands on all parts. Be careful, however, not to exert too much force on the tubes which are usually made of glass. Be careful also not to punch a hole in the cardboard cone of the loud speaker.

After the chassis is removed from the cabinet, you should place the control knobs back in place. Then connect the power plug and the antenna wire. Now you may try to operate the radio. The radio will *play* without the cabinet, but the tone will not be as good. After this second operating test, disconnect the radio once again.

WHAT THE KNOBS DO?

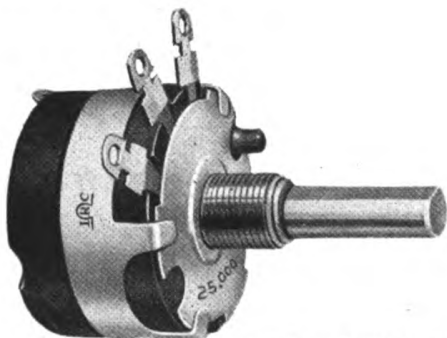


Courtesy Meissner Mfg. Co.

Figures 4 and 5. Here you have an illustration of a three gang variable condenser and an all-wave band switch.

WHAT DO THE KNOBS DO? Notice that the knob, which is used to tune in the radio station, is attached to a part made up of a group of movable plates. This part is known as a variable condenser. A three-gang type variable condenser together with associated coils is illustrated on this page. You will learn in later chapters how a condenser tunes in the wanted radio stations. The other knobs may control parts mounted under the chassis, and you may turn the radio over to find these parts.

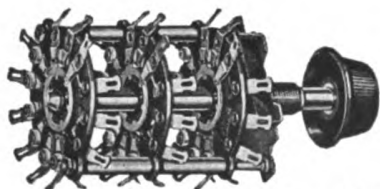
You must understand what part each knob controls and for what purpose this part is used.



Courtesy International Resistance Co.

Figure 6. A potentiometer, used to control the volume output of a radio set, may contain the power switch as in the unit illustrated.

The knob which controls the volume and the knob which changes the tone (if used) rotate the shafts of potentiometers, or variable



Courtesy P. R. Mallory & Co.

Figure 7. This is the kind of switch used in all-band radio sets and also in test equipment.

resistors. These units are discussed in great detail later and a typical potentiometer is illustrated on this page. Another knob controls a band-switch which is used to select the band of operation, i.e. broadcast, police, or short-wave.

A three deck switch is shown in Figure 7. Band-switches are obtainable with different number of decks and may have from two to about seventeen terminals per deck.

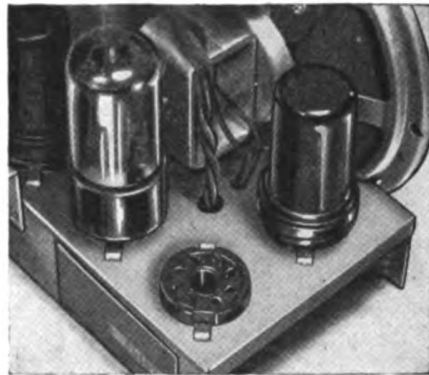
LEARNING THE NAMES OF PARTS

Make a list of the tubes used in the radio you are examining. If you have a very old radio, some of the numbers may be 227, or 280. In such cases, the hundred digit (2) is dropped, and the tubes are the same as modern type 27 and 80. Tubes for Sparton radios (old ones) are still numbered 182, or 484, and the complete number must be used.

A container that has but a single condenser usually has but two leads. Probably the filter condenser in your radio has several leads indicating that several condensers are housed in the container.

PARTS ABOVE THE CHASSIS. Now let us return to the top of the chassis. If you have a relatively modern radio, it will be somewhat like the set we illustrate. Observe the following parts with which we will now become familiar: vacuum tubes and sockets, filter condensers, cans containing coils, and the power transformer.

The vacuum tubes may be of various types and may have glass or metal envelopes. Examine with care the tubes used. Remove them one at a time. Notice how they plug into the sockets. Look under the chassis and see how a socket makes contact with the prongs of the tube. Notice the type numbers stamped on the tubes. Are any of the tubes in your radio marked with the type numbers: 6D6, 47, 6K7, or 80? How many prongs do the tubes have? Do some have more than others? Are all the prongs of any one tube of the same size? These are important facts and will help you study Lesson Nine where you will learn how vacuum tubes operate.



Courtesy American Phenolic Corp.

Figure 8. Radio tubes may be removed with an upward motion while slightly shaking your hand from side to side.

The filter condensers may be in various shapes. Sometimes they are supplied in metal containers mounted above the chassis. In other sets, the filter condensers may be in cardboard boxes mounted below the chassis. Locate the large filter condenser which is present in almost every radio.



Figure 9. Metal radio tubes have different physical appearances, but always use octal sockets.



Figure 10. Filter condensers are supplied in different containers.

You probably will find several light-colored metal cans mounted above the chassis. Keeping in mind the spot where the cans are mounted, turn the chassis upside down, and notice that there is a round opening directly under each can. Connecting wires come through this opening. By looking through this opening, you can see a radio coil inside the can. These cans are called shields by radiomen.

If your radio is designed only for A.C. (alternating current) power operation, you will find that it contains a power transformer. The type of transformer illustrated is known as a half-shell, but some radios use upright transformers.

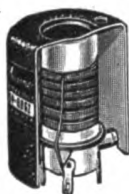


Figure 11. Radio coils are housed in metal cans.

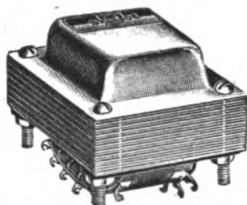


Figure 12. This illustration shows a half-shell power transformer.

UNDER THE CHASSIS. We now return to the parts under the chassis. Besides the sockets for tubes, potentiometers which we already mentioned, and switches, we find resistors of all types, and small condensers. Also there is a maze of wires inter-connecting

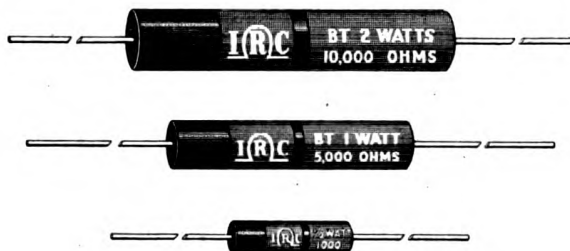


Figure 13. Carbon resistors are made in different resistance values and power handling sizes.

the equipment. Look carefully at all these parts and be sure that you can name all of them. This is what we have tried to accomplish so far. You must learn the names of parts, you must know the main points of appearance of every radio part before you can go on.



Figure 14. You will find many condensers of the type illustrated used in all radio receivers.

HOW THE PARTS ARE MOUNTED. Notice now how the different parts are mounted. It will be good practice for you to take a sheet of notebook paper and divide the page into four columns. Write the name of the part in the first column. In the next column describe how this part may be mounted or supported. Sockets may be riveted or bolted, resistors may be suspended on their lead-wires, etc. In the third column, you will suggest another method for mounting the same part if this is possible. And in the last column, you will state how many wire leads actually go to the terminals of the part. For example, a resistor may have only two terminals, but to one terminal there may be connected five different wires, while to the other only one. This will make six wires in all. Notice that every terminal of a part always has at least one wire.

HOW THE PARTS ARE MOUNTED

Some radio receivers, known as AC-DC types, do not have a power transformer. Sometimes these sets have a *heater* resistor in the power line cord. If this is true of your radio, you will notice the line cord becomes warm when the set is in operation.

The workmanship under the chassis will tell you about the quality of the receiver you have. The better sets have the parts neatly placed and sturdily held in place. The wire leads are short, direct, and well soldered.

ELECTRICAL FACTS

Many times metal parts of radio components are not in electrical contact with the circuits and do not carry any electric current. The frame of a power transformer or the metal shaft of a volume control ordinarily are not connected to the circuits of the radio.

In order to explain why certain parts are made entirely of metal, while others contain only small metal sections, and still other parts are made of bakelite, hard rubber, or cloth, we must present a brief theoretical explanation about electricity.



Figure 15. It is interesting to note that tube sockets may be mounted with bolts or rivets. A volume control is usually mounted by means of the threaded section around the shaft.

WHAT IS ELECTRICITY? Electricity plays an important part in making possible radio communication. In an ordinary house radio, electric power is changed in form, increased and decreased in voltage, and made to conform exactly to the electrical radio waves picked up by the antenna. We are able to control and use electricity to our advantage, but we have only a workable theory regarding the exact nature of this force.

According to this theory all matter is made up of 93 different atoms. These atoms, however, are in turn made up of identical negatively charged particles called *electrons* and heavier positive particles. We are primarily interested in the negative electrons since these make up the electric current.

The electrons are very small and millions upon millions are required to make up the current to keep a radio tube in operation. These electrons not only make up the atoms of matter, but are present as free electrons ready to move to any positive body which attracts them. In nature, negative particles, small or large, are attracted by positive bodies and repelled by other similarly charged negative bodies.

These free electrons tend to be present in equal quantity everywhere. If a body has too many electrons, they will move to other bodies to equalize this distribution. And for the same reason, a body short of free electron, will attract the electrons. This movement of electrons constitutes actual electric current.

CONDUCTORS AND INSULATORS. Electric current, made up of electrons, may pass along certain substances known as conductors. Silver, copper, and other metals are considered conductors. Many materials pass very little electric current. Known as insulators, these materials actually stop the current. Rubber, cloth, mica, slate, and many other materials are used to insulate radio parts.

If electric current is required to pass from one radio part to another, these parts must be connected by hook-up wire. On the other hand, if parts are not to be in electrical contact, they must be insulated. Separation is enough since air is a good insulator.

RADIO CIRCUITS. You have already learned that the various radio parts used in the receiver are interconnected with copper wire having either a cloth or rubber insulation. Radio engineers and repairmen must be able to obtain an understanding of the circuit employed in the radio set requiring adjustment or repair. This can be done by tracing out the various connections and making a pic-

Air separation or insulation with certain materials is sufficient if the voltages are small. Very high voltages will force a spark to jump across an air gap or puncture a thin piece of insulation.

ture of the parts and wiring. It is difficult, however, to make pictures of parts. When a picture drawing is finished, it is almost as confusing as the maze of wires one sees by looking at the bottom of a chassis. To simplify this task, radio engineers have decided to use symbols to represent the different radio parts. The connecting wires are represented by straight lines.

This is a logical solution. We are experienced in using symbols in almost all fields. The fact that an animal with four legs and of a certain appearance is called a dog and is spelled d-o-g, shows an application of symbols.

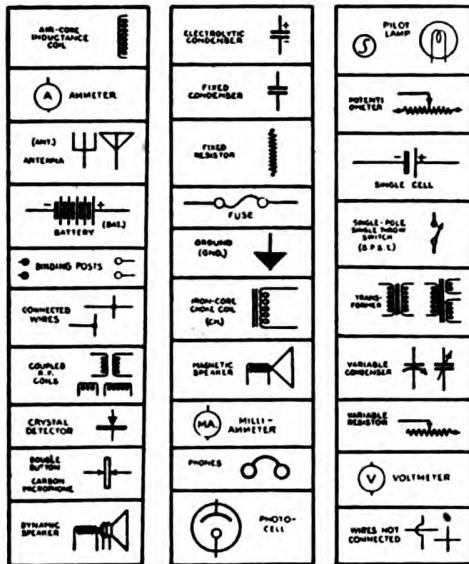


Figure 16. These are symbols of commonly used radio parts and must be carefully studied by you.

There are additional symbols besides those illustrated in Figure 16. Some of the symbols shown serve for similar components. For example, the symbol for an ammeter can be used for any meter provided the notation explains this. The scale of the meter, the value of a resistor, the voltage of a battery can be indicated with a brief notation along side the symbol.

The radio parts you have examined, as you read the first part of this chapter, all have easy-to-remember symbols. These symbols are illustrated and must be carefully studied. Practice making these radio symbols. You must be able to look at any radio part, call it by the correct name, and make a drawing of the proper symbol which is used to indicate this part in radio diagrams. A few additional symbols will come up as you progress with your studies.

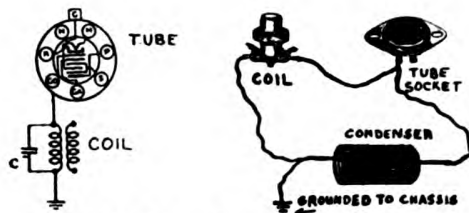


Figure 17. Please observe that the schematic and pictorial diagrams indicate the same connections.

Let us suppose that a certain radio set has a coil (inductance) terminal wired to a connection on a socket of a vacuum tube. How do you indicate this fact on a schematic diagram? You probably

CIRCUIT TRACING TECHNIQUE

For practice, the student should make the symbols of several radio parts (any parts at all) and inter-connect them in some fashion. Make another drawing of the same symbols (parts), but now connect them in the same *electrical* way using somewhat different pencil lines.

If color coded wires are used in your radio set, the task of circuit tracing is greatly simplified. Long nose pliers can be used to pull on the wire being followed, and this will show you the end terminal for the wire. Later on you will learn that an ohmmeter may be used as an aid in circuit tracing.

It is important that you follow the instructions and circuit trace sections of the receiver with which you have been working. Most radio repair jobs require some circuit tracing in locating the fault and you will find this practice very valuable.

know that first you will make the correct symbols for the particular coil and vacuum tube. Then you will draw straight lines, preferably with a ruler, connecting the proper terminals of these symbols. Examine the illustration showing this schematic drawing and also a picture representation of this wiring. Besides the parts mentioned, our schematic diagram also shows a condenser connected directly across one of the windings of the coil. Notice that this makes one side of the condenser common with the terminal of the vacuum tube.

In complete diagrams, straight lines are used to indicate the connections between parts, but these lines do not indicate the actual wires. The parts may be wired in any fashion as long as exactly the same component parts are connected with the lines and are also wired to permit the passage of current.

This example illustrates that the actual wires and the diagrammatical lines will permit the same passage of current and are, therefore, considered the same connections. But the lines are not exact representation of the wires for circuit tracing purposes.

CIRCUIT TRACING. A radio mechanic must be able to make a drawing of a circuit by examining the actual section of a radio receiver. He must also be able to locate connections and parts, shown in a schematic drawing, in the corresponding piece of radio equipment. Further, a great deal of radio servicing technique resolves around forming mental ideas of the circuits under test. Because of these facts, it is essential for a beginner to learn how to trace circuits.*

Let us assume that you are required to circuit-trace only a section of the radio set you are studying. This section may involve one of the tubes. If so, you have your starting point. Make a symbol for the socket used for this vacuum tube. This symbol may be a simple bottom view of the socket showing the openings for the prongs of the tube's base, or it may be a circle with the elements of the tube shown in a diagrammatical manner. See the illustrations used and also the details shown in Lesson Nine.

You now have a neat drawing of the tube socket in symbolic form. Start with any one terminal. If it has more than one wire connected, choose one only and see where it goes. Probably it will go to another radio part. Make a symbol for this additional part and use straight lines to connect the terminal of the socket to the correct terminal of this new part. Then proceed with other wires of this terminal and other terminals of the tube socket symbol. Remember that the lines need not be exactly like the wires; they must be only alike to the extent that will permit the same electrical circuit to exist.

Study again the illustration which shows in picture form the actual parts and wires, and the corresponding schematic drawing which shows the very same circuit. At times, two or more terminals of the same part may be connected together with a piece of hook-up wire. Usually it is important which terminal of a part is used for any one definite purpose. However, resistors and some condensers may be connected with their two terminals in either fashion for the same results.

*The Signal Corps uses the circuit tracing method of instruction in explaining operation, adjustment, and repair of radio equipment.

Spend as much time as you can circuit tracing sections of the radio receivers you have available. The connecting wires are sometimes colored to help you trace the connections. You may find that pulling on a wire you are tracing will make it easier to find the place where the wire terminates. Do not worry about the errors you may make in your drawings or the problems you may encounter and cannot solve. The additional knowledge you will acquire from the complete book will simplify the task of circuit tracing. We are anxious to have you obtain some experience in circuit tracing early in your studies.

REVIEW QUESTIONS AND PROBLEMS. 1. Make a rough sketch of the top view of the radio chassis you examined. Print in the names of the parts. How can you use such a sketch as an aid in getting the tubes back in the right sockets?

2. If the power plug is of the removable type, study the manner in which the cord is connected. Remove the cord with the aid of a screw driver and then re-assemble.

3. Using a small ruler, measure the inside diameter of the knob opening. While the knob is unmounted, turn-in the set screw until it becomes visible through the "shaft" hole.

4. Place your finger against the loudspeaker cone. Do you feel the vibrations which correspond to the sounds you hear? Does the tone change any because of your finger?

5. Do any of the tubes in your radio have a grid-cap connection at the top of the bulb? How is this connection made to the radio circuit?

6. What is the diameter of the coils used in your radio?

7. Why are rivets used instead of bolts in many cases?

8. Name three commonly used conductors of electricity.

9. Name three insulators used in radio parts.

10. Make a schematic showing two coils connected in a manner which will permit the current to enter one coil, pass on to the second coil, and then pass on to a long lead.

11. If two students wire two separate radios from a single schematic, will the radios match wire for wire? Explain.

12. What is the maximum number of wires which may terminate at a single point? What was the maximum number you found in your radio?

SELF-TESTING QUESTIONS

1. **Hint:** In lettering a radio drawing be sure that all printing can be read from the normal position or from the right hand side. See the drawing on page 179 of Volume Two.

4. Notice what part of the loudspeaker cone vibrates the most. Does this remain the same for high pitched and for low frequency sounds?

5. The grid caps are made in two different sizes for receiving tubes. Glass tubes require the larger size; metal and —G type tubes use smaller grid caps.

6. The diameter of the core of the coil is wanted. Probably anywhere from $\frac{1}{2}$ to $1\frac{1}{4}$ inches. Do not take any coils apart to get this dimension.

7. Probably quicker to fasten the parts.

8. Silver is often used for contact points on telegraph keys.

9. Are all these insulators suitable at high temperatures?

LESSON 2

Mechanics of Radio

This lesson will tell you what tools are needed to do radio work and how the mechanical operations of mounting, replacing, and repairing radio equipment are performed.

WHAT MAKES-UP A RADIO? A great many components are needed to make up a complete radio receiver. Usually we think of the radio as a unit having these components correctly inter-connected with wires. But it is also important to have these parts properly mounted. The parts must be mounted solidly and in positions to permit convenient and short connecting wires.



Figure 18. The components of a radio receiver must be assembled and properly wired to obtain the required operation. The photograph illustrates a radio class busy assembling simple radio receivers.

The tools illustrated at the right are required for successful radio repair work. Probably you are familiar with the use of these tools, but will find their application in radio work somewhat different. If you are not experienced in the mechanical work, it is advisable to get an old junk radio to practice dismantling the components and remounting a few of the parts in different positions.

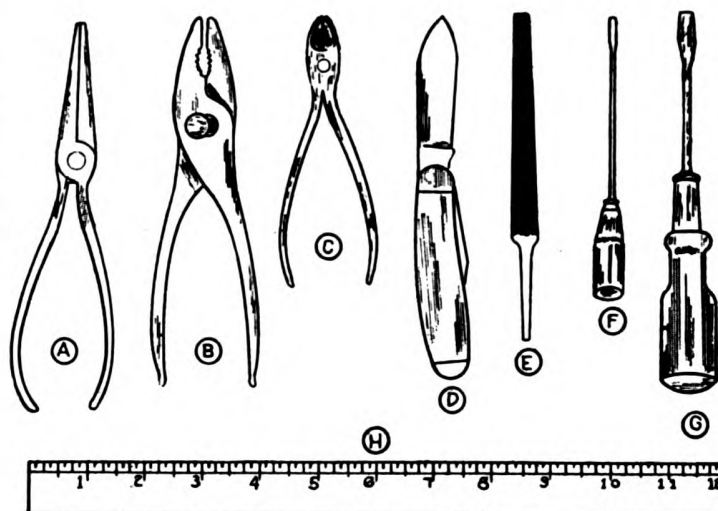
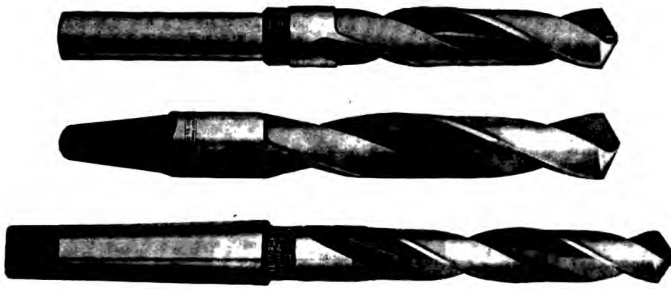


Figure 19. These are common radio tools needed for radio repairing and construction work. (A) Long-nose pliers, (B) Gas pliers, (C) Diagonal cutters, (D) Pocket knife, (E) Flat file, (F) Small screwdriver, (G) Medium-size screwdriver, (H) Scale.

METAL CHASSIS BASE. The radio parts are assembled on a metal base and are wired according to the circuit. The base is usually made of sheet metal which has been properly shaped, cut, punched and drilled. The metal used is usually cadmium plated iron alloy, aluminum, or galvanized sheet iron. As you have already seen in the radio you examined, the tube sockets are so mounted that the tubes are above the chassis. A few additional parts may be above the chassis, but most of the wiring and almost all of the smaller parts are placed below the chassis base.



Courtesy Cleveland Twist Drill Co.

Figure 20. Twist drills are used to make the needed holes in radio chassis bases.

If you are called on to make a chassis for a piece of radio equipment, the first step is to lay out the top allowing room for all parts to be mounted. Once your lay-out is completed, you will know what dimensions the top of the base will have. The sheet metal you will use must be laid out to allow about 2 inches additional along each edge for the sides of the chassis. Commercial chassis bases are available in many sizes and are reasonably priced.

If you are able to obtain some sheet metal and have the necessary tools, it is recommended that you make a small radio chassis. Plan to prepare this chassis for mounting upon it the radio parts that you have on hand. In obtaining a radio job, you may be questioned about the mechanics of radio to the same degree that you will be asked about radio theory.

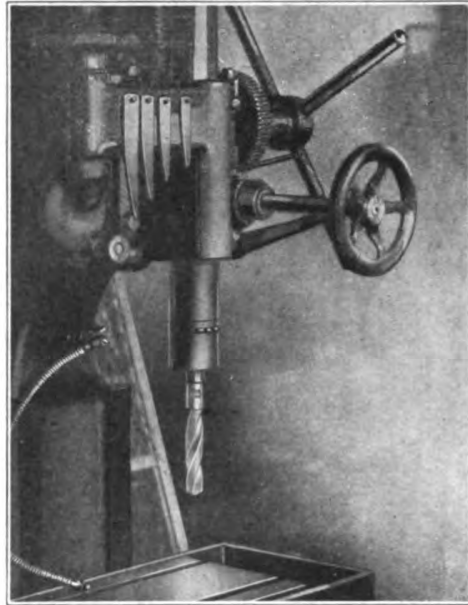


Figure 21. This type of socket punch is employed by radio servicemen and in experimental laboratories for punching the required cut-outs for tube sockets.

—Courtesy American Phenolic Corp.

Most radio parts are attached with bolts or rivets and, for this purpose, holes must be drilled. The correct twist drill for the job should make a hole just large enough for the threaded part of the screw to slip in. Self-tapping screws make threads in the metal as they are screwed in place. These self-tapping screws and rivets are used without lock washers.

Large circular holes may be made with a circle-cutter or with a socket punch. The punch may be in the form of a die. The socket punches are made in various sizes commonly needed for radio construction, while the circle-cutter is adjustable to various diameters.



Courtesy Cleveland Twist Drill Co.

Figure 22. For quickly drilling required holes, the drill press is very useful.

The planning of the placement of different radio parts on a radio chassis is made while considering many important factors. Parts that become hot in operation must be kept away from components such as condensers which are easily damaged by heat. All parts must be placed in relation to each other so that certain of the connecting wires are as short as possible. While all the wires should be short, you will learn later on that the grid and plate wires must be very short for proper operation of the equipment.

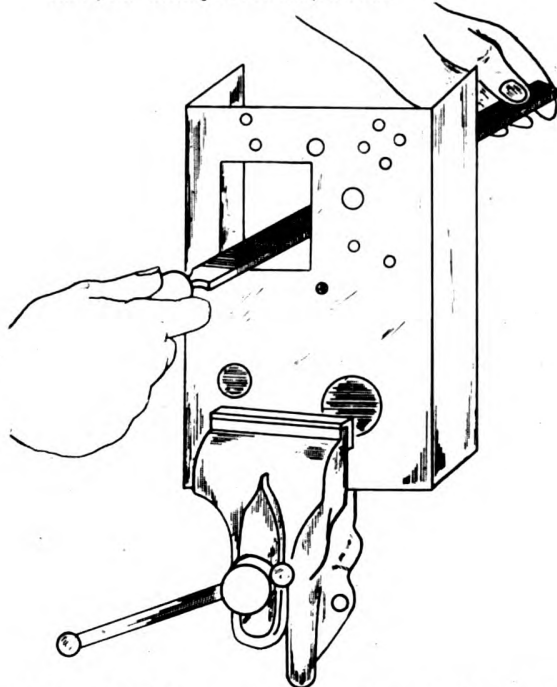
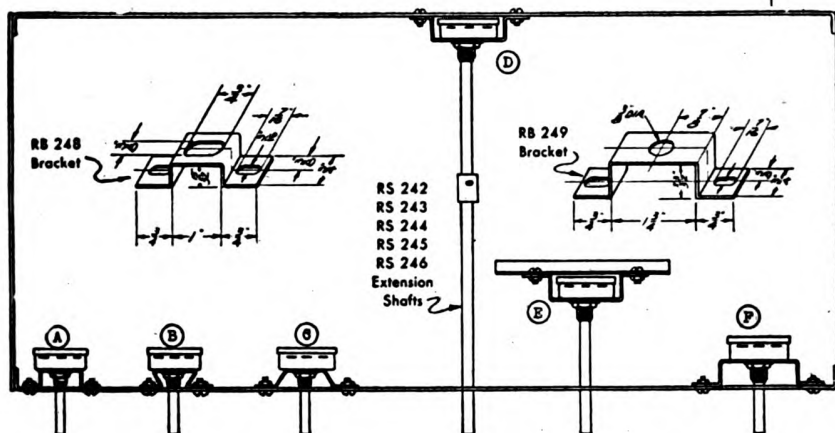


Figure 23.* When a square cut-out is made for mounting the transformer, the metal sides must be filed smooth.

*Figure 23 above, as well as Figures 19, 27, 29, 35, 111, and 115, are reproduced from "Mechanic Learner—Radio" which was issued by the Commonwealth of Pennsylvania, Department of Public Instruction, and was prepared with War Production Training funds in cooperation with the U. S. Army Signal Corps and the U. S. Office of Education.

In using a circle-cutter, care should be exercised in setting it to the exact dimensions needed. Of course, a hole cannot be made smaller, and only by difficult filing can the hole once drilled be increased in size.

Half-shell power transformers require rectangular openings in the chassis. The metal to be cutout is marked off and tiny (about $\frac{1}{8}$ inch) holes are drilled next to each other along the lines indicating the needed cut-out. After the holes are drilled all the way around, a chisel is used to cut the metal between the holes. When the job is completed, the rectangular blank will fall out. The opening is then filed smooth.



Courtesy P. R. Mallory & Co.

Figure 24. Volume controls may be mounted on special stand-off brackets as illustrated. However, in the majority of radio equipment, volume controls are mounted directly on the side of the radio chassis.

HOW RADIO PARTS ARE MOUNTED. Your attention was called to the method used for mounting radio parts, while you were studying in Lesson One. Small parts, such as resistors, condensers, and R.F. chokes, are supported with their own leads. Tube sockets are fastened to the chassis with machine screws or rivets. Large condensers (used in the power supply of receivers) are mounted with bolts or with stud-nut over the threaded section of the metal container. Power transformers are bolted in place, using the screws

MOUNTING RADIO PARTS

In some circuits, the volume control or other adjustable components are mounted some distance away from the front panel and the control knob on the front panel is attached to an extension shaft (either flexible or solid) as shown in Figure 24.

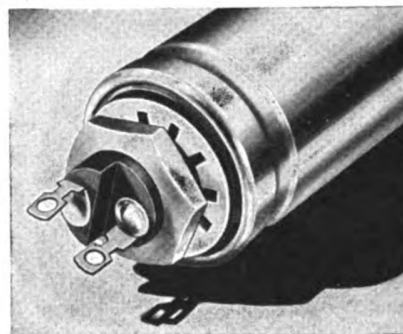


Figure 25. This is an illustration of an octal socket showing the two mounting holes. Sockets have different dimensions and the required holes must be drilled to measure.

that hold the frame to the laminations in the case of the half-shell type, or with machine bolts in case the transformer is of the upright type. Volume controls (potentiometers) are mounted behind the side of the metal chassis. The shaft comes through a threaded section which is attached to the case. This section is tightened against the chassis. The shaft may be cut to the needed length. The switch, used with many volume controls, is mounted in place on the back plate of the volume control unit.

HANDLING HOOK-UP WIRE

In many large sets, the ground bus wire (for all common chassis connections) may be bare.

No. 18 or 20 push-back wire will serve for most radio circuits. For some filament circuits, where currents of several amperes must be carried, No. 14 wire is recommended.

Wire connections should not rub against sharp metal parts since the insulation may be rubbed off with age and a short circuit will result. A short circuit is any unwanted connection that will prevent the proper operation of the equipment.

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MAKING WIRE CONNECTIONS. Radio parts are inter-connected with hook-up wire. The wire electrically joins the terminals to be connected. The hook-up wire should be insulated along its path, but is made bare and clean at the place where it comes in contact with the terminals. Push-back braided cotton covered wire is



Figure 26. Some filter condensers are supplied in cardboard containers with spade lugs for bolting the condenser to the chassis.

Courtesy P. R. Mallory & Co.

easiest to handle. Enough insulation is pushed back to make the needed connection, and then the insulation is pushed back over the wire up to the terminal. The illustration shows the proper method used for pushing back the insulation on both solid and stranded wire. When the insulation cannot be pushed back far enough with

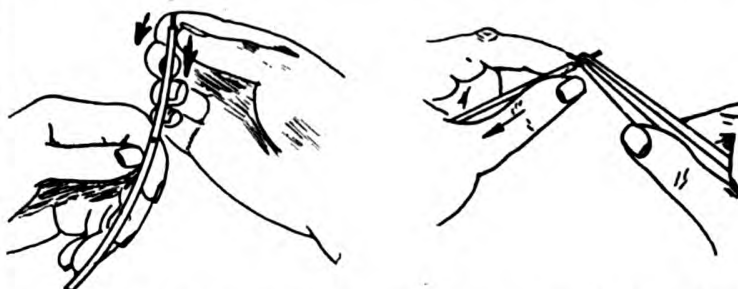
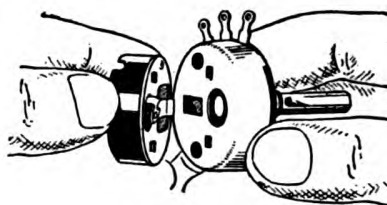


Figure 27. This illustration explains how you are to hold a piece of hook-up wire and push back the insulation. Once the bare wire becomes visible, the push-back insulation can be forced back a greater distance with the aid of long-nose pliers.

the fingers, it will be easier to grasp the bare end of the wire with long-nose pliers. Then, holding the wire in this manner, it is a simple matter to push the insulation back with the fingers as much as required.



Courtesy P. R. Mallory & Co.

Figure 28. The switch mounted in back of a volume control is removable, as illustrated.

Rubber covered hook-up wire and wire having rubber and cotton insulation is often used as the leads of radio parts such as transformers and filter condensers. The insulation is crushed with long-

nose pliers and then removed with diagonal pliers or a knife. Care should be taken that the wire is not nicked or cut in the process. Hook-up wire comes in sizes 16 to 20, B. & S. gauge.

The purpose of crimping wires to a terminal of any type is to insure a uniform, easily made, strong mechanical connection. If the terminal has a hole, the wire is bent into a half-loop with the aid of the long-nose pliers. After this, the tip of the wire is inserted

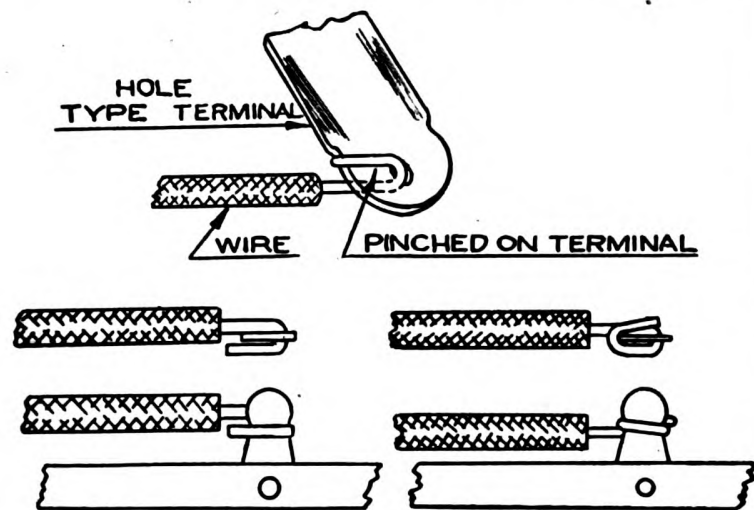
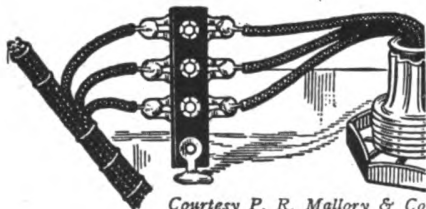


Figure 29. These several illustrations will explain how hook-up wire is attached mechanically to lugs or terminals. The contact must be made mechanically secure before solder is applied.

into the hole of the terminal, and the wire is squeezed (crimped) against the terminal. In case the terminal is of the lug type and does not have a hole, the wire is also made into a half-loop and crimped against the terminal. It is better to wrap the wire around the blank type terminal, crimping the wire from both sides.



Courtesy P. R. Mallory & Co.

Figure 30. In a radio receiver, wires are joined together at a terminal point or "lugs." Notice how the condenser leads are attached to extension wires using a terminal block.

SOLDERING. All electrical connections must be soldered to insure low resistance electrical contact under all conditions. Make it your rule to solder every connection you make, even if the equipment you are building is for temporary use.



Courtesy Drake Electric Works, Inc.

Figure 31. The 100 watt soldering iron is useful for radio work.

MAKING WIRE CONNECTIONS

You should practice handling different kind of hook-up wire. Practice stripping the insulation, bending the wire into required shapes to complete the connection, and crimping the wire to lugs and terminals.

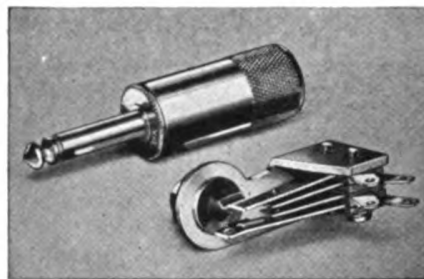
A mail order radio jobbers' catalog (available from several large radio dealers) shows illustrations of many terminals and will help you learn about the type of connectors and supports used in radio construction work.

SOLDERING PRACTICE

You should practice using *wire* solder and also regular bar solder and soldering paste. Unless you had extensive experience in soldering, you must spend hours perfecting your ability to solder quickly and expertly.

If you cannot obtain an electric soldering iron, or if you do not have power electricity in your community, be sure to obtain the needed soldering practice with a regular iron which may be heated over a stove or with the help of a blow torch. It is even harder to use a copper tip regular iron than an electric type, and so you will be getting even more extensive practice.

The best solder for radio work is made up of 63% tin and 37% lead, and has a melting point at 358° F. Solder cannot make a perfect bond with any metal when a layer of oxidation is present.



Courtesy P. R. Mallory & Co.

Figure 32. Connection to radio equipment may be made with the aid of plugs and jacks.

Flux, when heated, removes oxides and prevents oxidation during the soldering process. This enables the solder to adhere to the metal surfaces. Rosin flux should be used by a radioman. Acid flux has corrosive action and should not be employed. Most radio technicians prefer solder obtainable in the form of thick wire with a core of rosin flux. Because the rosin has a lower melting point than the solder, the rosin flows out first to clean the surface when heat is applied.

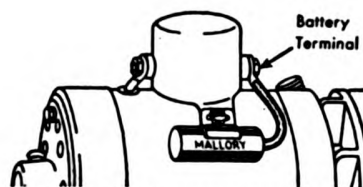
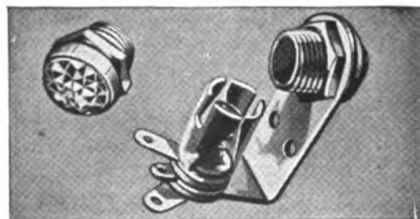


Figure 33. For some requirements, connections are made mechanically, secure and do not require soldering.

To provide the heat necessary for soldering, several methods are used. To solder exposed wire, where near-by parts cannot be damaged, a gasoline torch may be used. For most radio work an electrically heated iron is preferred. These irons are rated in watts of electrical energy they consume. A 100 watt iron is most popular



Courtesy P. R. Mallory & Co.

Figure 34. Bulls' eyes are used to indicate the presence of power in different circuits.

for radio work. The heating element of the iron is located inside the metal barrel. The heat travels to the copper tip which is used for soldering. Where electricity is not available, flame heated soldering irons are employed. These can be heated with a gasoline torch.

To do a good soldering job, the tip of the soldering iron must be properly shaped and tinned. Tinning an iron is a process whereby a thin, uniform layer of solder is formed upon the tip of the iron. The transfer of heat from the tip to the work occurs most easily if the surface is bright as the result of tinning. When the tip of the iron becomes "pitted" by the action of the rosin core in the solder, the iron must be filed and re-tinned. The iron can be kept clean for long periods of time by wiping the tip with a rag whenever corrosion accumulates.

The soldering iron must actually heat the joint to be soldered to a temperature that will readily melt solder. The solder will then run into each crack in the joint and form a good electrical bond. Hot smoothly flowing solder has a bright silver luster; as it cools, its appearance changes to a duller gray, setting shortly after this change. If the joint cools with a rough surface, the soldering job is not well done; a dirty contact, improper heating, or movement of the wires may have been the cause.

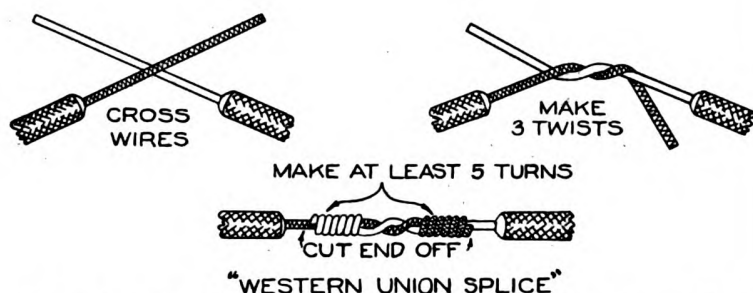


Figure 35. The *Western Union* splice is used to join wires outside of equipment and is made in the manner illustrated.

WIRE SPLICING. Splices are used to join two or more wires for the purpose of making an electrical connection. This connection should be mechanically secure and not require any mechanical fastening device. All splices should be soldered to assure continued good electrical contact. Splices are found in antenna connections and in telephone lines. In a radio chassis, the junction should be made at a tie-point or a terminal. For all splices, the bare ends of the wire must be cleaned before the splice is made. Solder is applied. The bare parts of the splice are taped with electricians tape to complete the job.

REVIEW QUESTIONS AND PROBLEMS. 1. Using your radio set as a guide, lay out a drawing of the chassis indicating all dimensions and places for all holes. Sections of the chassis which cannot be reached, may be omitted.

2. What are the advantages of rivets over machine bolts in mounting radio parts? What are the disadvantages?

3. Why is hook-up wire usually insulated?

4. Explain how you would tin an iron?

5. If you have had but little experience in soldering, obtain bits of wire, an old chassis base or piece of galvanized iron, some old radio parts, and practice soldering. Only practice can make you expert in soldering.

USES OF WIRE SPLICES

If the point of the iron becomes pitted, a smooth metal file is used to remove the foreign deposit and shape the copper point. The iron may be locked in a vise or may be held by the handle and rested against a metal surface.



Courtesy Aircraft-Marine Products, Inc.

The solderless terminals illustrated are easily attached to conductors with special crimping tools. Several terminals can be used to form a junction on a single stud block.

1. This drawing should be made large and neat. A piece of light colored wrapping paper, 17 x 22 inches, is excellent for this purpose.

2. Do you, as a future radio and electronic equipment repair man, prefer rivets or bolts? Why?

3. Stiff bus-bar wire may be used bare, but the hook-up wire employed in radio equipment is not stiff enough.

4. Go over all points in detail. Actually do the work before writing the answer in your notebook.

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LESSON 3

Mathematics of Radio

Good practical men have failed to perform relatively simple radio tasks because they lacked the knowledge of elementary mathematics and could not use basic radio formulas. Enough mathematics has been included in this course to give you the essentials of the required mathematics.

If you had very little arithmetic in school or have forgotten this work, please write to M. N. Beitman, care of the publishers, and enclose a statement of your training and present knowledge in arithmetic and algebra. We will recommend an inexpensive supplementary book to help you. Please enclose a self-addressed and stamped envelope for a speedy reply.

WHY MATHEMATICS? The work of radio engineering is accomplished with the aid of mathematics. Practical radio tasks can be performed without the aid of mathematics. But the knowledge of a few simple formulas and the most elementary mathematical operations will enable you to save time on many jobs and will eliminate trial and error attempts and guess work.

For example, if you wish to install a transmitting antenna, you may try various lengths until the best results are obtained. A more sensible method is to use the correct formula, substitute for the letters the known facts about the station transmitter, and solve for the exact size of antenna required.

Mathematical formulas are short-hand statements of facts about radio physics. A simple formula interconnects facts and permits you to find the value of one of the facts when the others are known. The actual facts, of course, are numerical quantities expressed in suitable units. We are going to assume that you have forgotten the mathematics you may have studied at school. We will begin with simple arithmetical problems and help you to grasp the mathematics you will need to be successful in doing practical radio work.

NUMBERS. There certainly is nothing hard about numbers. Since you have been a small child, you have been counting 1, 2, 3, 4, 5. Later at school you learned the multiplication tables. You learned that all numbers can be formed from the symbols, 1, 2, 3, 4, 5, 6, 7, 8, 9, and 0. The zero is important since it really enables us to write all numbers with only ten symbols. And you better remember that multiplying any number by zero, or multiplying zero by any number, results in zero.

FUNDAMENTAL OPERATIONS. There are four fundamental operations. You have used them in school and in every day business. One of these operations is *addition*. Addition means to combine items. Only similar items can be combined. If one radio set uses six (6) vacuum tubes and another employs five (5) tubes, by adding ($6 + 5 = 11$) we learn that the two radios together require eleven tubes.

Subtraction means to take away, to remove one quantity from another. If you had a dozen machine bolts and used three in mounting a radio chassis, then you would have nine bolts left.

$$12 - 3 = 9$$

After your wages are computed, the amount for Old Age Pension is deducted (subtracted), and you receive the balance.

Multiplication is a process of continued addition. By memorizing tables, the work of multiplying is greatly simplified. Number 8 multiplied by number 6, is equivalent to adding number 8's six times. The symbol $\times$ stands for the multiplication operation. The statement

$$8 \times 6 = 48$$

is read: Eight times six is equal to forty-eight.

If two letters are written next to each other, but without a symbol between them, these letters are to be multiplied together. For example, fL means f multiplied by L. Sometimes a dot like this • also stands for multiplication.

Division is the inverse of multiplication. You read

$$24 \div 6 = 4$$

as: Twenty-four divided by six is equal to four.

This problem may also be stated as:

$$\frac{24}{6} = 4$$

Please notice that this means that the quantity above the long dash is to be divided by the number below the dash-line. Most formulas which involve division are written in this manner.

FRACTIONS. Many times in radio work, quantities are parts of a whole unit and are called fractions. $\frac{1}{2}$ volt is a part of an electrical unit known as a volt. The number written behind a slant-line, as the 2 in $\frac{1}{2}$, or below a long dash is called the denominator. It tells into what portions the entire unit is divided. The number in front of the slant-line or above a long dash is called the numerator. This number tells us how many of the parts are included. For example, the fraction $\frac{5}{8}$ tells us that the division is made into eight parts, and that five of these parts are included. Since in this fraction there are eight parts in all, and five are included in the fraction we are considering, three more such parts would complete a unit. This means that $\frac{3}{8}$ more are needed to make $\frac{5}{8}$ a complete unit. And we add these fractions by combining the numbers in the numerators, keeping the same denominators which must be alike to permit addition. From this we see that $\frac{8}{8}$, or for that matter any fraction whose numerator and denominator are equal, is really one whole unit.

We have tried to recall a few facts about fractions to you. Most practical radio problems are worked in decimals and are of such simple nature that very little additional knowledge of fractions is needed.

DECIMALS. We write whole numbers in the regular way and place a period, called a decimal point, at the end. For example, the number forty-eight is written as 48. Fractions must be changed to have a denominator of 10, 100, 1000, or some larger number of this type involving 1 followed by zeros. If the fraction is $\frac{2}{5}$, it may be changed to $\frac{4}{10}$, and is written as .4; this means that the number after the decimal point is the numerator of a fraction whose denominator is 10. The number 2.57 is read as two and fifty-seven hundredths. Notice that there are two figures after the decimal point and this accounts for the "hundredths."

Decimals are more convenient to use than fractions. Multiplication or division by ten, or some multiple of ten, simply shift the decimal point. The number 2.57 when multiplied by 100, simply requires the shifting of the decimal point to the right two places to correspond to the two zeros of the 100. The answer is 257. If this original number is divided by 100, the decimal is shifted to the left two places and the answer is .0257, the extra zero must be placed to show that the decimal point was moved two places to the left.

FRACTIONS AND DECIMALS

To add or subtract fractions, the denominators must be alike. If they are not alike, a number is selected which can be divided by both denominator numbers. If the smaller denominator goes into the larger, this larger denominator is the one you want. The number of times the denominator goes into this common number, is the factor for multiplying the numerator (top) and denominator of the fraction considered. For example, the fractions may be $\frac{1}{3}$ and $\frac{2}{5}$. Both denominators will go into 15, and this is the smallest number that will permit division by both 3 and 5. The number 3 will divide into 15, five times. Therefore, the fraction $\frac{1}{3}$ must be multiplied by five, resulting in $\frac{5}{15}$. Notice that both the denominator and numerator are multiplied by this factor. In a similar way, 5 (the other denominator) will go into our selected number 15, three times. We now multiply the second fraction, $\frac{2}{5}$ by three, and obtain $\frac{6}{15}$. The denominators are now alike and they may be added or subtracted as required. If they are added, the result is $\frac{11}{15}$. Only the numerators are added, the common denominator is kept for the answer. If these fractions are subtracted, the result is $\frac{6}{15} - \frac{5}{15} = \frac{1}{15}$.

When two fractions are multiplied, no such changes are needed. The numerators are multiplied together and form the new numerator. Also the denominators are multiplied separately and form the denominator of the answer. For example, $\frac{1}{3} \times \frac{2}{5} = \frac{2}{15}$.

ELECTRICAL UNITS

When powers of ten (such as 10^3 , 10^7) are to be multiplied, the exponents need only be added together to obtain the power of ten of the answer. For the example, the answer would be 10^{10} .

The unit of electric charge equal to about 6.3×10^{18} free electrons, is called a coulomb. The ampere is a unit of electric flow. The passage of one coulomb past a given point in one second represents an ampere.

It is important that you visualize voltage as electrical pressure. This electromotive force may be generated by means of chemical batteries, rotating magnetic machines known as dynamos, or by heating the contact point of two different metals.

HOW TO WRITE LARGE NUMBERS. In radio work many times very large numbers must be expressed. A special short-hand method for doing this is used. When any number is multiplied by itself, it is said to be squared, or raised to the second power. For example, 10 times 10, which equals 100, may be written as:

$$10 \times 10 = 10^2$$

The little number two is called the exponent and indicates how many tens have been multiplied together. In the same manner, 10^3 would indicate $10 \times 10 \times 10$, or 1,000. A million can be written as 10^6 . You will notice that the exponent also indicates the number of zeros in the number.

Now if we have a number as 240,000, it may be written in our short-hand as: 24×10^4 . This means that the original number is equal to 24 times 10,000 and the 10,000 may be written as ten to the fourth power.

ELECTRICAL UNITS. For comparative purposes of the qualities encountered in electrical circuits, selected units are employed. These units are inter-related and are based on absolute basic reactions. Because of the nature of electricity and the associated force, magnetism, we cannot measure or note these forces directly with our senses of touch, sight or smell, but must resort to indirect indicators (meters, lights, etc.) operated by these forces.

CURRENT. Electric current needed to light an electric bulb or to heat the filament of a radio tube consists of millions of moving electrons. A practical unit of electric current is an ampere which represents the passage of a tremendous number of electrons per second. It is easy to see that when one circuit has a current of 15 amperes, it has five times as much current as another circuit which has only 3 amperes.

While in power work an ampere is a convenient unit, some radio circuits have very little current, sometimes only a thousandth or a millionth part of an ampere, and a smaller unit is more applicable. A milliamperes* is one-thousandth of an ampere. It takes 1,000 milliamperes to make up one ampere. A microampere* is one-millionth part of an ampere. It takes one million microamperes to add up to a single ampere. Formulas usually are expressed in amperes of current, and if the problem has other units of current, these must be changed to amperes.

VOLTAGE. The force which produces current (electron movement) from one body having an excess of electrons to another body having less electrons, acts as a pressure. This electrical pressure is called electromotive-force and its unit of measure is the volt. You know that an ordinary battery dry cell used in flashlights has an electromotive force of $1\frac{1}{2}$ volts. At times electromotive force is abbreviated EMF, and may be called voltage, potential difference, or just potential. In radio work, we use voltages from a few volts up to 1,000 volts. A thousand volts is also known as a kilovolt*. Very small potentials are measured in microvolts and millivolts.

RESISTANCE. The unit of resistance is the ohm. Special units having very high resistance are used in some radio circuits. In case the resistance runs past one million ohms, it is expressed in megohms. A megohm is equal to one million ohms. The concept of resistance will be presented in Lesson Four.

*The prefix *milli* means one-thousandth part, *micro* means one-millionth part, and *kilo* means one thousand times.

FORMULAS. Mathematics is a symbolic way of explaining and analyzing physical occurrences. Arithmetical numbers represent quantity. Ten volts is ten times the standard measure—the volt. Numbers tell how many, is it larger or smaller, is it too small . . . all these are measures of quantity. Algebraic symbols (usually letters of the English and Greek alphabets) represent specific measurable quantities. For example E usually stands for voltage in electrical work. This is really another way for writing “voltage,” i.e. we say E instead of the word voltage. In a like manner we usually write I for current, and R for resistance. A Greek letter π appears in many radio formulas and is a constant always equal to 3.14.

Using letters saves time and greatly simplifies the writing of formulas. The Ohm's Law may be written in words as:

$$\text{Voltage} = \text{Current (multiplied by) Resistance}$$

$$E = I \times R$$

or in algebraic symbols directly under. Of course, the algebraic way of writing is much simpler to write and remember.

Sometimes in the same problem, there are two different voltages, such as the grid and plate voltages in a vacuum tube. Here again we may use some letter, as “E,” to represent voltage and use small letters after E and a little below it, to stand for grid and plate voltages respectively. As:

$$E_g \dots\dots \text{grid voltage}$$

$$E_p \dots\dots \text{plate voltage}$$

HOW TO USE FORMULAS. There are many practical formulas which you will have to use in your work. You will find every formula a short-hand statement of facts. Study this statement (formula) so you understand it. Now determine what fact is unknown and must be found with the aid of the formula. Leave the letter representing this fact alone, and consider the other letters. Each letter represents some other fact about the circuit or problem. Find the numerical value of these facts, but make sure that they are in the units required. If the formula requires current to be in amperes, and the problem mentions the current in milliamperes, change the milliamperes to amperes by dividing by a thousand (one thousand ma. equals an ampere). After making these numerical substitutions simply solve for the unknown letter. This calls for getting all numbers on one side of the equal sign, and keeping the unknown letter alone on the other side.

GRAPHS. Certain facts may be best represented or analyzed by presenting the data in the form of a graph. A graph shows the relation between two facts or group of facts. As for example, the graph illustrated represents the rise of current in milliamperes through a 1,000 ohm resistor, as the voltage is increased from 0 to 100 volts. The voltage is plotted as the ordinate (vertical scale) beginning with 0 and running up by equal subdivisions to 100 volts. The current begins with 0 and increases to the right; it is plotted as the abscissa (horizontal scale).

This graph illustrates that the current varies directly with the applied voltage (varies in a straight line). For a 1,000 ohm resistor values of current may be obtained for any voltage covered by the scale, and vice versa. At 50 volts, for example, following the dotted line, the value for current is 50 milliamperes.

Additional mathematical facts will be presented in connection with problems as they come up in later chapters. The student

There is no special reason why certain letters should be used for definite electrical quantities in electrical formulas, but usage dictates certain choices. Usually the letter employed is the initial of the term. For example, R for resistance, E for electromotive force. Since C stands for capacity, the letter I, was selected for current.

The unknown quantity should remain alone on one side of the equal sign of the formula; all other terms should be on the other side. If the formula in this form is not known, the regular equation expressing these facts can be solved by algebraic operation to take this form.

The financial pages of large city newspapers have graphs to illustrate certain price trends. While these have nothing to do with radio, you will find it good practice to examine and study these graphs.

REVIEW PROBLEMS

1. You probably recall that any number multiplied by zero results in zero. Also remember that division by zero is impossible.

2. You should get an answer of 24 inches, or 2 feet.

3. You still have 98 feet left.

4. See the explanation on page 23. Your answer should be $5/6$.

5. Each group of eight men will have one iron.

6. Divide 1 by 3. Do this by long division. Place a decimal point after 1., and add zeros. The answer: .3333 etc.

7. 4×10^6 .

8. This is 60 ma.

9. This is a quarter of a megohm, or 250,000 ohms.

10. E_r is commonly employed.

11. 2,260.8 is the answer.

should review arithmetic and elementary algebra in any standard text-book if he has difficulty following the practical mathematics which are included in this chapter.

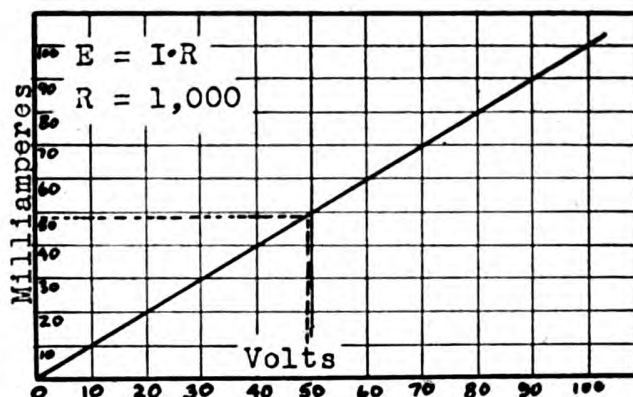


Figure 36. This graph illustrates the relationship between voltage and current in a circuit which contains a 1,000 ohm resistor.

REVIEW QUESTIONS AND PROBLEMS. 1. If 10,000 is multiplied by zero, what is the answer?

2. To wire a radio set the following pieces of wire are needed: 3 inches, $3\frac{1}{2}$ inches, and $13\frac{1}{2}$ inches. The mechanic knows that the extra amount for bending around terminals is usually 20% additional. How much wire will be needed for the job?

3. From a roll of wire initially having 100 feet, six pieces of 4 inches each are cut. Remembering that 12 inches equals one foot, how much wire is left on the roll?

4. Add $\frac{1}{2}$ and $\frac{1}{3}$.

5. A Signal Corps Company consists of 256 men and is supplied at a certain time with 32 soldering irons. One soldering iron is expected to serve how many men?

6. Write $\frac{1}{3}$ as a decimal correct to two places.

7. Express four million in short-hand notation.

8. How will you write .06 amperes in milliamperes?

9. A resistor of 0.25 megohms, is how many ohms?

10. What is a logical symbol-letter for filament voltage?

11. If a formula states that $X = 6.28 \times f \times L$, and f is 60, and L is 6, what is X ?

12. Refer to the graph illustrated in this chapter, and plot in it the points corresponding to 75 volts and 50 ma., and 90 volts and 60 ma. Connect these two points with a straight line.

LESSON 4

Circuits Using Resistors

RESISTANCE. Even the best electrical conductors such as silver, copper, and aluminum, oppose the passage of electric current. Insulators have so much opposition that we say that they do not pass any electricity at all. Iron wire is not an insulator, but it is a much poorer conductor than the metals mentioned. One may think of iron as having greater opposition to the passage of electric current—greater *resistance* to the freedom of electric current movement. Copper has little resistance. Wax paper has very high resistance. In general, the better conductors have very little electrical resistance, the insulators have very high resistance.

RESISTANCE AND THE SIZE OF THE CONDUCTOR. If a piece of copper wire has a definite resistance, a piece twice as long will have twice the resistance. A piece of wire may be thought of as a water pipe. Any pipe has opposition to the passage of water. If the pipe is made twice as long, somewhat as in the above example, the opposition or resistance will be doubled.

If you cut a piece of wire with a very sharp tool and looked right at the side of the cut, you would see a circular cross-section of the wire. This cross-section has a definite area. Now if the wire is made thicker, the cross-section will be increased and a larger path will be provided for the movement of electrons forming the electric current. A larger path will offer less resistance. This illustrates that two wires made of the same material have resistance, per unit length, inversely proportional to the cross-section area. The thicker the wire, the less resistance.

UNIT OF RESISTANCE. We already learned that the unit of resistance is the *ohm*. Hook-up wire, No. 18 B. & S. gauge, has a resistance of .0065 ohms per foot. A mile of this hook-up wire has a resistance of about 34 ohms. The cloth insulation of this same wire has insulation-resistance which is measured in millions of ohms.

The electrical resistance of most substances varies with temperature. Electrical conductors made of metal have an increase in resistance as the temperature is raised. However, this change is small and may be ignored in practical radio work.

COMPOSITION-TYPE RESISTORS. Carbon is a fair conductor and, therefore, has low resistance. Bakelite and many other plastics have very high resistance. If we take powder made of carbon and mold it into the shape of the resistors you examined in the radio set, we will find this "resistor" will have a very low value of resistance. The "resistor" made from the bakelite powder, on the other hand, will have very high resistance. Now we can mix the two powders in any proportion we wish and, by this means, produce any value resistor needed. The carbon type resistors used in radio are actually made in this fashion and the connecting leads are attached to both ends.

The metallized resistors have the mixture, which will give the desired resistance value to the finished product, baked on an insulating form. Usually these resistors are coated also with a ceramic insulation material and this permits mounting the resistors near metal parts without the possibility of a short circuit occurring.

You should realize that when the diameter (or radius) of a piece of wire is doubled, the cross sectional area is increased four times.

This means that the same conductor may have higher resistance if the surrounding temperature is increased.

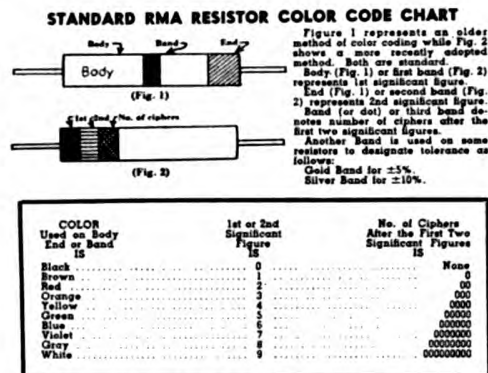
While the commercial carbon composition resistors are made in this fashion, the actual materials used are not necessarily bakelite and carbon, but may be other forms of powdered conductors and insulators.

In small midget radio receivers, many parts are placed very close together and insulated resistors are recommended.

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The range of these carbon resistors runs between 100 ohms and 20 megohms. As you probably know, one megohm equals one million ohms. Carbon resistors are capable of handling only small amount of electrical power and this subject is discussed later in this chapter.

RESISTOR COLOR CODE. The composition resistors are color coded in a special way to indicate the resistance value of the unit. Study carefully the chart illustrated below. You need not memorize these facts, but you should practice using the color code chart until you are expert at this work.



EXAMPLE: Take the number 62,000. 6 is the first significant figure, 2 is the 2nd significant figure and the number of ciphers after the first two significant figures is 4.

Figure 37. Carbon composition resistors are color coded to indicate their resistance value. You must practice using this code so that you are proficient in telling the value of resistors upon examination.

For practice, you may determine the actual sizes of the carbon resistors used in your radio receiver. Use the color code. In some units, a small dot is used instead of the center band.

As another example, let us suppose you find a resistor all red. There is no visible dot or end color. You may, in this case, assume that both the end and dot are also red and, therefore, could not be painted on the red body. Now to find the actual resistance value. The red body tells us that the first figure is 2. We assumed the end is also red, that makes the second figure also a 2. The dot is also red. This means that there are *two* more *zeros*. The total value is 2,200 ohms.

MECHANICS OF COMPOSITION RESISTORS. These resistors are one-half to two inches long and have leads of tinned copper wire. These leads are about two inches long. Usually the resistor is mounted directly between the required terminals. If the leads are too long, they may be shortened. If the bare leads pass close to other non-insulated parts, a sleeve of insulation material should be placed over the bare leads. If the two terminals for the resistor, which is to be mounted are far apart, find a supporting dummy terminal of some sort near one of the required terminals. Mount the resistor on these two supports. Then wire the dummy terminal to the second required terminal using a piece of hook-up wire of the proper size. Terminals of parts not used and not connected in any way may be used as dummy supports. (For example, extra terminals on tube sockets.) On a socket for a 6K7, the number six terminal is not used for any purpose and can be employed as a support. Special stand-off brackets with several terminals are also available for this purpose.

At this point, it is worth while to go back to the midget radio set you examined before and find the size of each resistor using the



Courtesy General Radio Company.

Figure 38. Sensitive test equipment, as the impedance bridge illustrated, is used to test various radio components. The proper operation of any radio device depends on the correct function of each part incorporated.

color code and also notice the method employed for supporting the carbon resistors used. Do you think the radio set you are using was assembled in good style?



Figure 39. Some radio sockets are supplied with several of the terminals already interconnected as may be required in a particular circuit.

INCREASING RESISTANCE. It is possible to increase the resistance of a carbon resistor by cutting several notches with a file in the body of the resistor. Since these notches will make the cross-section area somewhat smaller, the resistance will be increased. In a later chapter you will learn how to measure the resistance with an ohmmeter, and this instrument will permit you to know just how much of a change you may make with this trick method.

The degree of accuracy used for testing radio components depends on the application. When radio parts are to be used for research or laboratory experiments, special sensitive test units are employed to detect possible faults and to determine the exact size of the units.

Do not try to increase the resistance of a unit more than 20%. It is better to cut several notches instead of a single large one.

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ACCURACY OF RADIO PARTS

You recall, of course, that 100% is the entire quantity, while 1% is one-hundredth part of the total.

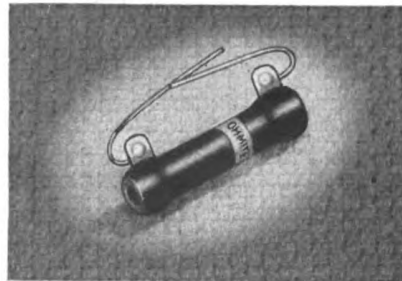
ACCURACY OF RESISTORS. One percent of any amount is one-hundredth part of this amount. Ten percent is 10/100 of the particular amount being considered. Most commercial carbon resistors are accurate to within 10% of the marked or indicated value. This means that any resistor may be of a resistance value 10% larger or smaller than the value indicated by the color code. A resistor of 50,000 ohms, plus or minus 10% accuracy, may be anywhere from 45,000 to 55,000 ohms. Please remember that the value may be anywhere between these two extremes and, by chance, may be very close to 50,000 ohms. Consider several of the resistors you found in the radio set as being of 10% accuracy, and calculate between what limits of resistance they may actually be.

Probably you are somewhat surprised that radio parts can be so much off the required value and yet give good results in the circuit. Not all sections of a radio receiver permit such variation in resistance values. However, carbon resistors are usually employed in circuits where several values of resistors would work successfully. An audio amplifying tube may have a resistor connected between its terminal known as the cathode and the chassis which serves as the ground or grid return circuit. A 1,000 ohm resistor would serve the purpose. But a 2,000, or 3,000 ohm resistor would give



Figure 40. Certain circuits require the use of resistors of very high accuracy. A precision resistor used in meter circuits is illustrated.

as good operation and you could not tell the difference. Even 5,000 ohm resistor would give fair operation. Now if we choose a 2,000 ohm resistor for this purpose, and remember that it is only 10% accurate, we realize that actually we may be placing into the circuit a resistor having a value anywhere between 1,800 and 2,200 ohms. But from our explanation we can see that any of these values will give proper results.



Courtesy Ohmite Mfg. Co.

Figure 41. This is a type of wire wound resistor employed in radio circuits.

Many times, very sensitive electronic equipment will give excellent results with resistors of commercial accuracy. It is the circuit that determines the requirements and not the function of the complete unit.

The fact that a piece of equipment is intricate or expensive does not indicate that very accurate resistors are needed. The circuit application of the part determines the accuracy needed. For meter multiplier circuits, for example, resistors accurate to within 1% are usually used. Most, ordinary radio equipment is so designed that resistor values are not critical.

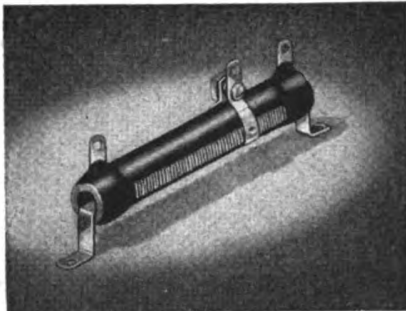
WIRE-WOUND RESISTORS. When resistors must handle greater power or have better stability, they are made of high resistance nichrome or similar wire. Commercially, these resistors are made by winding the wire on strips of fiber or porcelain tubes. The turns are separated from each other. The type of resistance wire employed, thickness of wire, and total length used, determine the resistance value of the finished unit. These resistors are usually encased in a protective coating of baked enamel or special cement. This covering protects the fine resistance wire and prevents resistance changes which may occur due to moisture.



Courtesy P. R. Mallory & Co.

Figure 42. Usually wire wound resistors have a metal band on which the value and description of the unit are stamped.

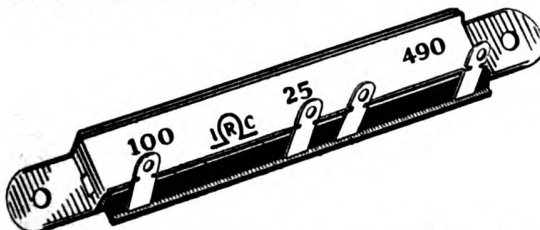
Usually the resistance wire is started and terminated in suitable connector-lugs. Sometimes extra connections are made in the middle of the resistor by means of extra terminal-lugs. Semi-variable type wire-wound resistors have a bare strip along the length, which is not



Courtesy Ohmite Mfg. Co.

Figure 43. Some wire wound resistors have adjustable taps. The set screw holding the band of the tap must be loosened before the contact is moved.

covered with the insulating cement, and permits contact with the resistance wire. Sliding lugs are used to make contact with the wire and the connections may be adjusted for the resistance value needed. Examine the illustrations included.



Courtesy International Resistance Co.

Figure 44. Some fixed resistors are supplied with several fixed taps to give different resistance values.

RESISTORS FOR HIGHER POWER



Courtesy Clarostat Mfg. Co.

By combining a number of variable resistors connected in series, it is possible to obtain any value of resistance needed for test purposes. One knob controls a potentiometer of 10 ohms, and permits adjustment in steps of one ohm, up to 9 ohms maximum. The next unit permits adjustment in steps of 10 ohms, up to a maximum of 90. The next control permits adjustment in steps of 100 ohms each, up to 900 ohms. In this manner, any needed resistance value can be obtained. The complete unit is called a decade resistance box.

Wire-wound resistors should not be supported on their leads alone, but should be held in place on support legs as shown in Figure 43, or soldered to stand-off lugs.

VARIABLE RESISTORS

The arm of the rheostat should be in contact under pressure with the wire element. Good, positive contact will prevent arcing and will increase the life of the unit. The contact pressure may be checked and adjusted. A little vasoline may also be applied to the surface.

The terms *rheostat* and *potentiometer* have been loosely employed in literature. The correct definition of a rheostat implies a continuously variable resistor having two terminals. A potentiometer has three terminals. Sometimes, however, all heavy duty variable resistors are called rheostats, even if they have three connecting terminals.

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Wire-wound resistors are made in resistance values from a fraction of an ohm to about 100,000 ohms. It is not practical to make these resistors in higher resistance values. Physically resistors are made in various sizes to serve different heat or power dissipating requirements. Wire-wound resistors of the larger size are supplied with mounting-feet and are bolted to the chassis.

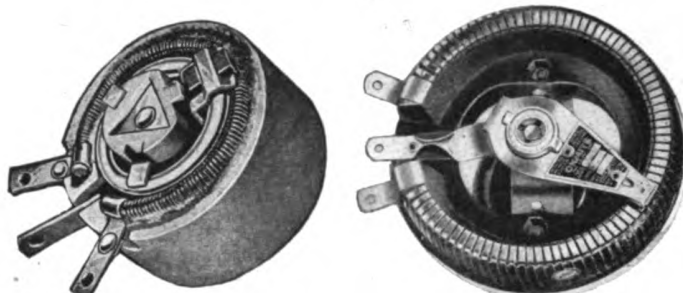
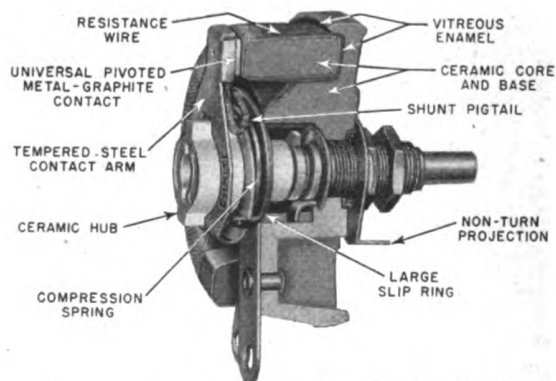


Figure 45. The heavy-duty rheostats illustrated are employed in circuits where a quick change of resistance is needed from time to time.

VARIABLE RESISTORS. In many radio applications the value of a resistor must be changed for the purpose of adjusting the circuit. When you turned the knob to change the volume output of your radio, you really were adjusting a resistor. Variable resistors are made so that a sliding contact, easily controlled by means of a knob, permits the changing of the resistance value between almost zero ohms and the maximum resistance incorporated in the unit. Such units require but two terminals. One terminal is the end connection, the other is the sliding contact. When the sliding arm is near the fixed terminal, the resistance is at a minimum. As the arm is moved away, the amount of resistance between the arm and the fixed terminal increases. Such units are known as *rheostats*. Usually rheostats are made in low resistance values and are used to control power circuits.

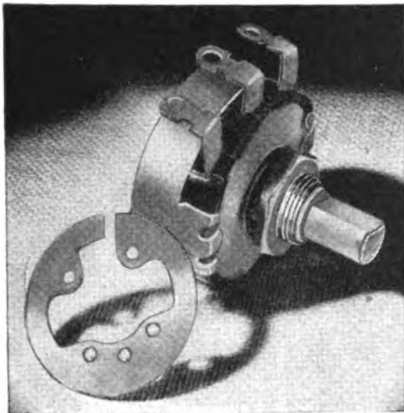


Courtesy Ohmite Mfg. Co.

Figure 46. A cross-section of a rheostat illustrating the manner of assembly.

POTENTIOMETERS. Potentiometers are very similar to rheostats, but have three connecting terminals. Both end terminals are used, and the third terminal is connected to the movable arm. As the resistance between the movable arm and one of the fixed terminals is increased, the resistance between the arm and the other fixed terminal is decreased. These two sections of resistance always add up to the total resistance marked on the potentiometer.

Most potentiometers are mounted on the side of the chassis and require a single $\frac{1}{2}$ or $\frac{3}{8}$ inch hole. Several makes of potentiometers have an extra rib which requires a small hole besides the large one. This protruding rib prevents the entire unit from re-



Courtesy Clarostat Mfg. Co.
 Figure 47. Potentiometers are used to control and adjust radio circuits. Notice the slotted shaft for a special knob. The resistance element is illustrated separately.

volving as the shaft is turned. The shafts of potentiometers are supplied quite long and must be cut to size. Since very soft metal is used, the job is easily done with a hack-saw. Sometimes the shaft comes notched in many sections and this permits breaking off the extra length with a pair of pliers. You may also remove the extra length by filing a little all around the point where you wish to break the shaft. Use a small three-cornered file for this purpose. After filing, grasp the shaft with a pair of pliers on each side of the cut. Two pairs of pliers will be needed. A side twist with the pliers and the extra portion of shaft will break off.

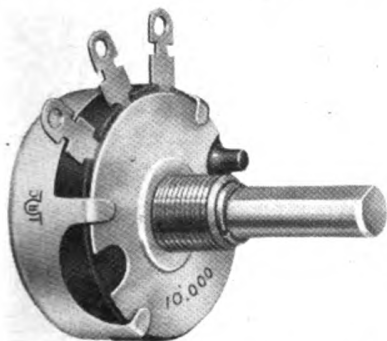


Figure 48. Potentiometers are used as volume controls in radio receiving sets. Notice the threaded section around the control shaft. This section is placed through a hole in the side of a chassis and a nut is employed to tighten the potentiometer in place.

Courtesy International Resistance Co.

Potentiometers are often called volume controls since they are used for this purpose in radio receivers. However, this is not a good name since potentiometers are also used for adjusting tone control circuits, oscilloscopes, test instruments, and for hundreds of other applications.

Some potentiometers are made with resistance wire in a manner similar to wire-wound resistors. Wire-wound potentiometers are used primarily where low value resistance units are needed and electrical power is handled by the circuit. The values of wire-wound potentiometers are between several ohms and a maximum of about 10,000 ohms. Potentiometers using a carbon deposit as

RADIO POTENTIOMETERS

Some potentiometers use very special type of shafts. If the correct replacements cannot be secured, you may make a repair with a potentiometer of the correct type, but with a standard shaft. This regular shaft is cut short and a section of the original special shaft is cut off and attached to the unit.

Two nuts may be used to mount a potentiometer a short distance behind the chassis. First, one bolt is *screwed on*, then the potentiometer is placed through the opening in the chassis, and the second bolt is used to tighten the assembly in place.

POTENTIOMETER CONNECTIONS

In some battery sets, the switch mounted on back of the potentiometer is of a dual type — it controls two individual circuits at the same time. Such a switch may have three or four connecting terminals.

You must understand that the total resistance between the two extreme potentiometer terminals remains almost constant at any setting of the arm. The moving contact, connected to the center terminal, *moves* between these two fixed extreme connections. As the moving arm may be rotated closer to one fixed terminal, and thereby, reduce the resistance between this terminal and center connection; the resistance between the moving arm and the remaining fixed terminal will correspondingly increase.

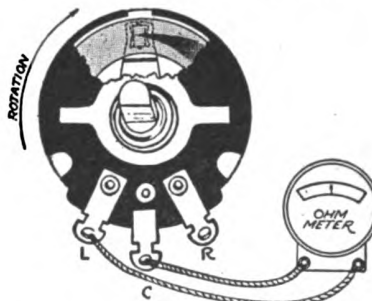
the resistance element are used more commonly and are obtainable in resistance values from 1,000 ohms to 10 megohms.

Since potentiometers are the units used for adjusting the circuits, they receive much mechanical use and are a source of trouble. Occasionally, the control may be opened and repaired by bending back the rubbing prongs of the rotating arm and cleaning the carbon element. Usually it is best to replace the faulty unit.

In a few units, the arm, having the center terminal for its connection, is grounded to the shaft and the metal framework of the potentiometer. But in most units, the elements of the potentiometer are entirely insulated from the metal framework. The "on-off" switch for the equipment may be placed on the back of the potentiometer and the first rotation of the shaft will operate this switch. Remember that this switch has no electrical connection with the resistance element of the potentiometer.

CONNECTING THE POTENTIOMETER. You know that a potentiometer has three terminals. The center terminal is connected to the movable arm. It is indicated in the symbol for a potentiometer as the center arrow. The choice of the other two terminals, however, is very important. Assume that you are holding a potentiometer in your left hand with the shaft pointing directly at your face, and the connecting terminals at the bottom of the unit. Now turn the shaft all the way to the left, counter-clockwise. There is now almost no resistance between the terminal on the left and the center terminal. But between the right hand terminal and the center terminal there is a maximum resistance. Now as you rotate the shaft to the right, clockwise, you increase the resistance between the left terminal and center, and decrease the resistance between the right terminal and center arm.

Usually the output of the radio equipment is increased as the control knob (on the shaft of a potentiometer) is turned to the right, clockwise. And the potentiometer must be connected so that the circuit will be changed by the right hand rotation of the slider to increase the output. You will be able to apply this knowledge when you begin to study actual radio circuits.



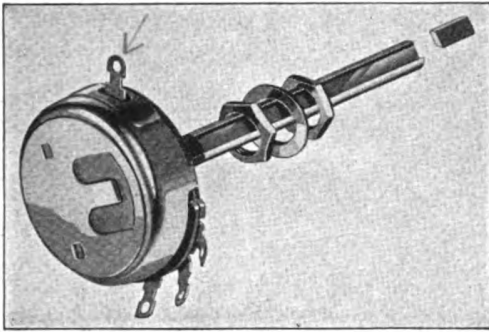
Courtesy P. R. Mallory & Co.

Figure 49. An instrument used to measure resistance, called an Ohm-meter, is employed to determine the total resistance of a potentiometer and the taper incorporated.

TAPER. Let us consider what resistance we will get between the left-hand terminal and the center terminal for different positions of the rotating arm. If we start with the rotating arm in the extreme left-hand position, we will have about zero resistance. Actually, in high resistance potentiometers, this minimum resistance may be several hundred ohms. Since we have not as yet turned the shaft,

we can call this position of the rotating arm 0% of the effective rotation from left to right.

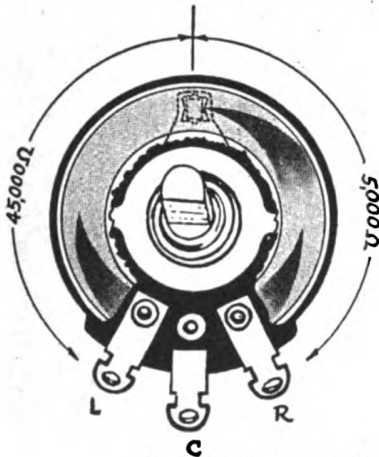
TYPES OF TAPER



Courtesy P. R. Mallory & Co.

Figure 50. Potentiometers are supplied with long shafts which can be easily cut to the size required.

If the potentiometer we are using for our example, is made of a *uniform* deposit of resistance-carbon material, at the mid-point of rotation (corresponding to 50% of effective rotation) we would have one-half of the total resistance of the unit. This potentiometer



Courtesy P. R. Mallory & Co.

Figure 51. In the potentiometer illustrated, the total resistance of 50,000 ohms is divided as shown to give a non-linear taper.

has a *linear taper*. This means that the resistance between the terminals we are considering varies linearly (directly) with the rotation. At 75% effective rotation, i.e. three-quarters around to the right, we will have three-quarters of the total resistance. If the unit we are using is a 10,000 ohm potentiometer, then at the 75% effective rotation setting, we would have 7,500 ohms resistance between the terminals.

NON-LINEAR TAPER. For most control applications non-linear taper types of potentiometers are needed. These potentiometers do not have equal change of resistance for equal changes of rotation. In some of these units, the first 50% of rotation brings only a very small change in resistance between a set of terminals, but the bulk of resistance change occurs at the end of the rotation. In other potentiometers, a great deal of resistance change occurs as the rotation is started, but then the change becomes gradual. Study the

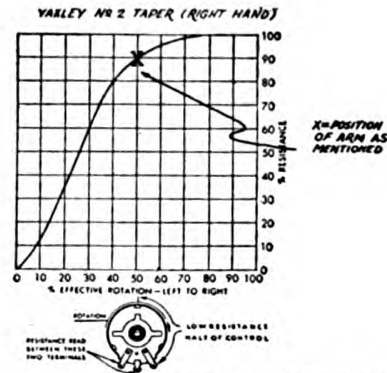
The potentiometer illustrated in Figure 50, is interesting because it has an extra tap connection. This tap is a fixed connection to a point along the resistance element. This extra connection is useful in special circuits and for tone-quality automatic adjustment with volume setting.

You may understand the meaning of *linear taper* a little better if you will realize that adjustable wire-wound resistors have uniform taper — equal resistance change for equal movement of the adjustable slider.

RESISTORS IN SERIES

Beginner radio students often wonder what faults in operation are noticed if a replacement potentiometer has the correct resistance value but the wrong taper for the application. Usually, the equipment will operate, but the tone or volume level adjustment with the replacement potentiometer will be difficult. The settings will be critical and the useful portion of the total rotation will be very small.

curves showing the various tapers. Later you will understand in what type of circuits the different tapers are used.



Courtesy P. R. Mallory & Co.

Figure 52. This is the taper for the potentiometer shown in Figure 51.

RESISTORS IN SERIES. Two resistors may be connected, one after the other. This is a *series* connection. More than two resistors may also be connected in series. In radio work, resistors of various sizes are connected in series. The value of the equivalent resistance of the circuit formed by several resistors connected

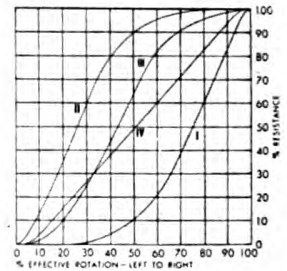


Figure 53. Potentiometers are made in various resistance values and tapers. Some commonly employed tapers are illustrated in the graph.

Usually, when two or more resistors are connected in series, an additional connection is made to the junction point. However, resistors may be connected in series to give a value of resistance not obtainable in a single unit, to give greater power handling ability than is obtainable from a single resistor, or to reduce the total voltage placed across each resistor, and in each of these cases *no* additional connection need be made to the junction of the units.

in series is obtained by adding the resistance values of all individual resistors. For example, if a 200 ohm and a 450 ohm resistors are connected in series, the equivalent resistance of the combination is 650 ohms. In mathematical terms, the total series resistance R_s equals the sum of the resistors making up the network, and these resistors may be R_1 , R_2 , R_3 , etc.

$$R_s = R_1 + R_2 + R_3 + \dots$$

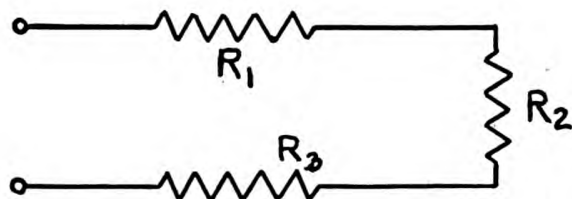


Figure 54. Several resistors may be connected in series. The total resistance is the sum of the individual resistors. The current in every resistor is the same, but the voltage drop across each resistor will be different, unless the resistors are all alike.

Resistors are connected in series to give values of resistance not obtainable in a single resistor. For example, 170 ohms can be obtained by connecting in a series a 100 and 70 ohm resistors, since no single 170 ohm resistor is commercially available. Sometimes resistors are connected in series to provide a tap-connection between the resistors.

RESISTORS IN PARALLEL. Suppose we wire two resistors in such a fashion that one of the terminals (leads) of each resistor are joined together, and also the other leads are joined. The current in this type of network will pass through each of the resistors. This connection places the resistors in *parallel*. The equivalent resistance will be less than the value of the smallest resistor. Several resistors may also be connected in parallel. The equivalent total resistance of several resistors connected in parallel can be calculated from this formula:

$$R_p = \frac{1}{\frac{1}{R} + \frac{1}{R_2} + \frac{1}{R_3} + \dots}$$

Usually not more than two resistors are wired in parallel and the formula simplifies to:

$$R_p = \frac{R_1 \times R_2}{R_1 + R_2}$$

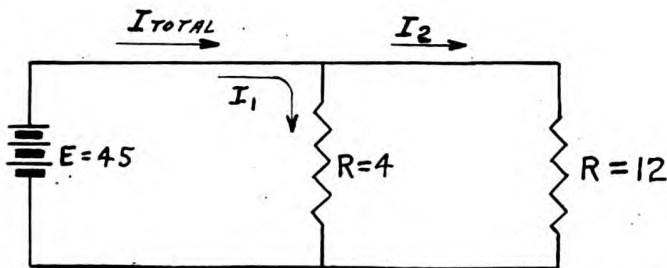


Figure 55. Two or more resistors may be connected in parallel. In a parallel resistor circuit, the voltage across each resistor is the same, but the currents may differ.

If we connect a 4 and 12 ohm resistor in parallel, we can use this formula to find the equivalent resistance. R_1 will be 4 ohms, and R_2 will be 12 ohms. Substituting in the formula, we obtain:

$$R_p = \frac{4 \times 12}{4 + 12} = \frac{48}{16} = 3 \text{ ohms}$$

This means that these two resistors connected in parallel will act as a single 3 ohm resistor.

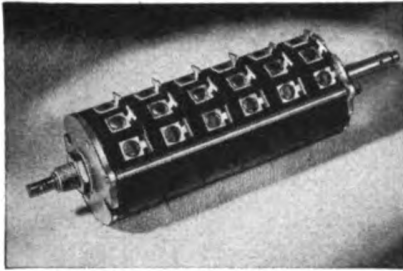
Usually only identical resistors are connected in parallel. If two 600 ohm resistors are connected in parallel, the equivalent resistance is reduced to one-half (divided by two since there are two resistors) of the 600. The resistance is then 300 ohms. If three such 600 ohm resistors are connected in parallel, the equivalent resistance is 600 divided by 3, or 200 ohms. In such case, each resistor handles its proportion of power.

RESISTORS IN PARALLEL

In practical electronic and radio circuits, parallel connection of resistors are not employed very often. However, in analyzing the function of many circuits, one often finds the equivalent of parallel combinations of resistances. The same simple mathematical formulas can be applied in either case.

If the two resistors connected in parallel differ greatly in resistance values (for example, one ten times larger than the second), the equivalent parallel resistance may be assumed equal to the smaller unit.

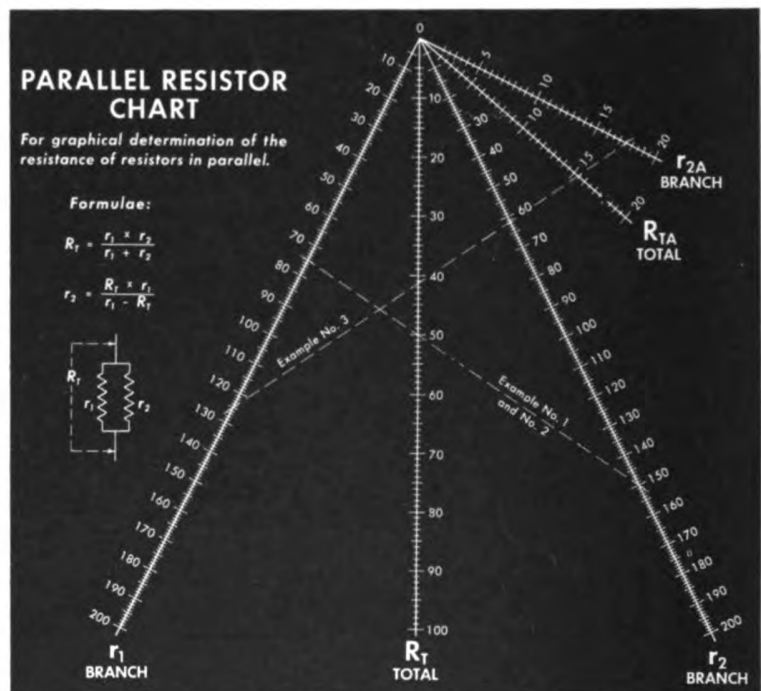
SAVE TIME WITH CHARTS



Several potentiometers may be operated in *parallel* mechanically, but the electrical connections may be independent or may be interconnected in any needed fashion. A control of this type is illustrated.

It is recommended that you set the larger value of the two parallel resistors on scale r_1 . If the values cannot be found on the scales, multiply or divide (as the case requires) all resistors considered by 10, or 100, or larger multiples of 10. Whatever operation you do to the original resistor values which are being considered as making up the parallel resistors, you must do the *reverse* to the equivalent parallel resistance, R_T . If the resistors are divided by 100 (say they are 8,000 and 12,000 ohms), the answer as read on the scale must be multiplied by 100, in this example.

HOW TO USE THE PARALLEL RESISTOR CHART. This alignment chart enables graphical solution of problems involving resistances connected in parallel. The values of the parallel resistors r_1 and r_2 and of the total effective resistance R_T must be read on the scales marked with the corresponding letters. To use, place a ruler across the two known values; the point at which the ruler crosses the third scale will show the unknown value. Pairs of resistances which will produce a given parallel resistance can be obtained by rotating a ruler around the desired value on scale R_T . The range of the chart can be increased by multiplying the values on all the scales by 10, 100, 1000, etc., as required. Scales r_{2A} and R_{TA} are used with scale r_1 when the values of r_1 and r_2 differ greatly.



Courtesy Ohmite Mfg. Co.

Figure 56. This handy chart will enable you to solve parallel resistor circuit problems with ease. See text for details.

Example No. 1. What is the total resistance of a 75 ohm resistor and a 150 ohm resistor connected in parallel? Answer: From dotted line No. 1, R_T is 50 ohms.

Example No. 2. What resistance in parallel with 750 ohms will give a combined value of 500 ohms? Answer: From dotted line No. 1, r_2 is 1,500 ohms.

Example No. 3. What is the combined resistance of 1,750 ohms and 12,500 ohms? Answer: Scales r_1 and r_{2A} are used and from dotted line No. 3, R_{TA} is 1,535 ohms.

Example No. 4. What is the combined resistance of 400, 600 and 800 ohm resistors in parallel? Answer: First find R_T for 400 ohms and 600 ohms. Then set the 240 ohms thus found as a new r_1 and 800 ohms as r_2 and the final answer is found to be 185 ohms.

COMBINATION CIRCUITS. In circuits where more complex combinations of resistance are present, usually it is possible to solve individual parts of the circuit and combine results. This process is best illustrated with an example*.

In circuit A, we may consider R_2 and R_3 as parallel resistors.

$$R_{23} = \frac{R_2 R_3}{R_2 + R_3} = \frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2 \text{ ohms}$$

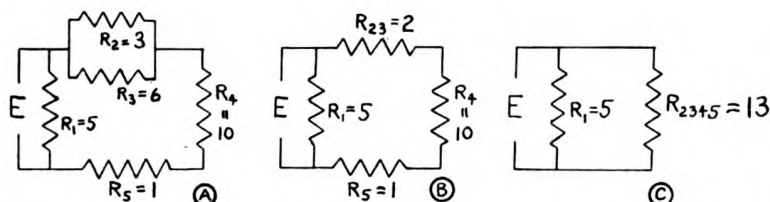


Figure 57. Certain more complex resistor networks can be solved in steps, using the parallel and series formulas.

Now we can replace circuit A by B, placing a single resistor R_{23} in place of R_2 and R_3 . Consider now R_{23} , R_4 , and R_5 as a single series circuit.

$$R_{2345} = R_{23} + R_4 + R_5 = 2 + 10 + 1 = 13 \text{ ohms}$$

We now can replace B, with circuit C. This circuit is a simple parallel circuit having two resistances of 5 and 13 ohms.

$$\text{Total equivalent resistance} = \frac{5 \times 13}{5 + 13} = \frac{65}{18} = 3.6 \text{ ohms}$$

BATTERIES. An important source of electrical energy for portable radio equipment is the electric cell or battery of cells. A cell is a unit "battery" that produces electrical energy by means of chemical action. A battery is a combination of two or more cells connected in series or parallel. A primary cell is a unit which produces electric pressure (voltage) because of a chemical reaction. Once the chemically active materials are used up or an equilibrium is reached, no further appreciable current can be obtained.

CIRCUITS AND BATTERIES

The solution illustrated will require the least amount of mathematics. There are other methods which lead to a group of simultaneous algebraic equations.

Single cells are often called batteries, but this is not correct.



Figure 58. In localities where electric power is not available, storage batteries and dry batteries supply the power needed to operate radio equipment.

DRY CELL. The ordinary flash-light cell is of this type. The larger batteries used in portable sets, rural-district radios, and Signal Corps portable equipment, are made up of a large number of such

*This example taken from: *Practical Radio Mathematics*, M. N. Beitman, 1941, Supreme Publications.

CONNECTING DRY CELLS

The life of a dry cell depends on the amount of electric current *taken* and how the current is removed. A cell will last longer if the current taken is not excessive and there are idle periods between times current is consumed.

cells. This "dry" cell has an outside foil of zinc which acts as the negative electrode. The center positive electrode is made of carbon. There is also a chemical solution in paste form. Additional chemicals are included to give the cell longer life. These cells produce about $1\frac{1}{2}$ volts. The larger ones, of course, can supply greater

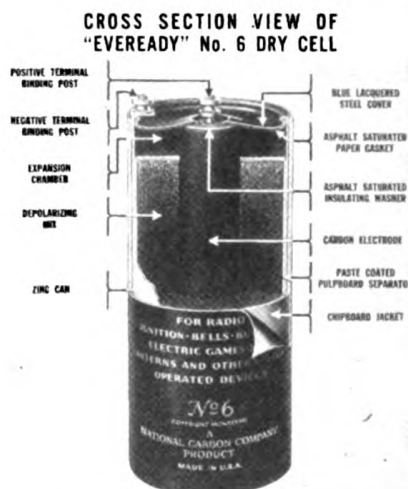


Figure 59. Inside view of a dry cell, showing the construction and materials used.

If several cells are available for an application requiring but one, do not keep the balance as spares, but connect all cells in parallel. This will reduce the drain from each cell. Batteries have a definite *shelf-life*, and will go dead within a year.

current and will last longer than smaller size cells. All the cells produce the same voltage. The cells are connected in series and parallel to supply various requirements.

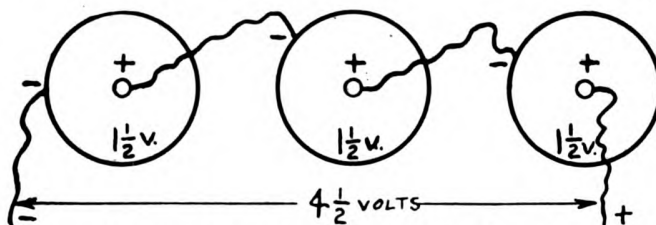


Figure 60. Several dry cells can be connected in series. Greater voltage can be obtained with this connection, but the life of the cells is not increased.

STORAGE BATTERIES. The lead storage battery is used in connection with some radio equipment. It consists of a positive plate of lead peroxide and a negative plate of spongy lead. These plates are placed in a solution of dilute sulphuric acid.

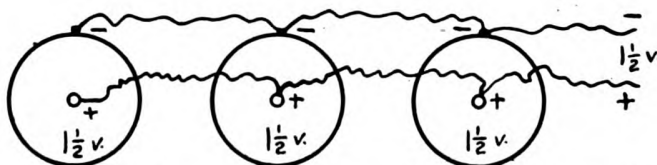
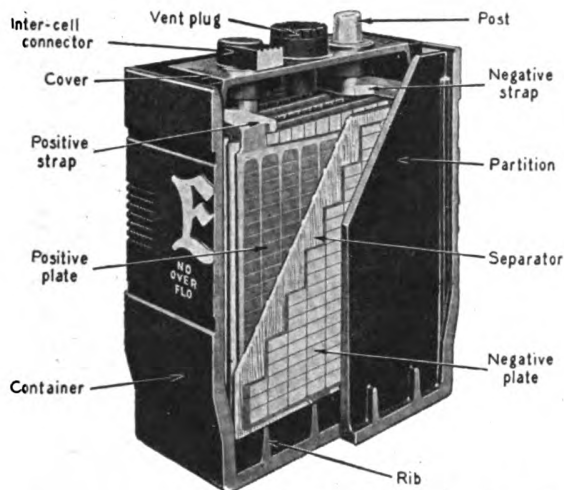


Figure 61. Dry cells may also be connected in parallel. The usual $1\frac{1}{2}$ volts will be obtained, but the life of the cells will be increased. With this circuit, higher current may be taken.

The storage battery is a secondary battery because it cannot produce electric current of itself, but must be *charged* at first. The charging current is "stored" and may be obtained from the battery

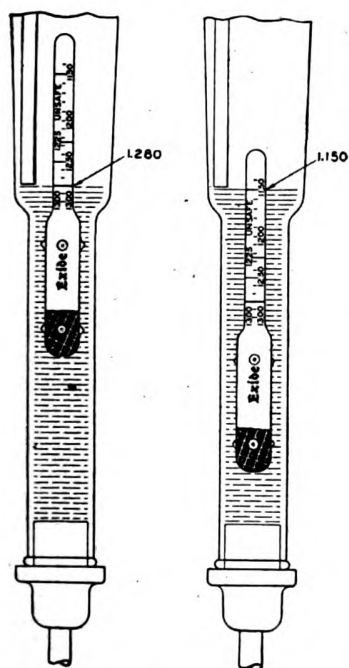
STORAGE BATTERY TESTING



Courtesy Electric Storage Battery Co.

Figure 62. A cross-section view of one cell of a storage battery. Notice how the positive and negative plates are interlaced.

when needed. The battery actually does not store electricity, it stores chemical energy produced by the charging current. When the current is used during the discharge period, this chemical energy is used up. Radio storage batteries are tested with a hydrometer since the specific gravity (lifting power) of the solution changes



Courtesy Electric Storage Battery Co.

Figure 64. The reading on the float of a hydrometer, in line with the liquid from the storage battery, indicates the condition of the battery "charge."

Only water need be added since sulphuric acid employed in the solution has a very high boiling point and does not evaporate to any degree.

Storage batteries are rated in ampere-hours of capacity. This figure tells the number of amperes for the period of hours the battery will supply. Roughly, a 100 ampere-hour battery will deliver one ampere for 100 hours, or 5 amperes for 20 hours, or 8 amperes for about 12½ hours.

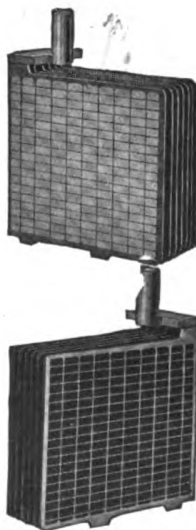


Figure 63. Positive plate above and negative plate below.

CIRCUIT CALCULATION

Radio and electronic components must be connected in some fashion to give the required operation. On this page, we are considering the first complete and, perhaps, applicable circuit. An electrical circuit consists of several parts connected to permit the passage and control of electric current in the required manner.

The predetermination of electrical values in a circuit permits the proper design for the purpose on hand. While the analysis presented on these pages is simple, it is the basis for all circuit design and understanding.

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with the "charge" condition of the battery. The float in the hydrometer should have the number 1.275 on the level with the acid solution taken from a fully charged battery. The battery must be recharged when the level reaches the 1.150 point. Additional charge may be given to the battery any time it is not fully charged.

The batteries are recharged with special equipment which may operate from the 110 volt A.C. power line, or may be a gasoline-motor driven generator. In an emergency, a storage battery may be charged from a 110 volt D.C. line (direct current) by connecting the battery in series with a large size electric light, or several lights in parallel. Proper polarity, of course, must be observed.

CIRCUITS. We are now ready to deal with a real but simple electrical circuit. Let us connect enough dry cells in series to obtain 45 volts. Since each dry cell produces $1\frac{1}{2}$ volts, a total of 30 cells will be needed to make up this battery. The symbol for all batteries is the same, but the figures written along side can be used to indicate the voltage. Since voltage or electro-motive force is abbreviated E , we can write $E = 45$. Now let us connect a 15 ohm resistor across this battery. Notice how this is done in the schematic drawing. In actual practice you would use two pieces of insulated wire to make these connections. The symbol for all fixed resistors is the same, but here we can write $R = 15$, to indicate that the resistor is 15 ohms. This completes our circuit.

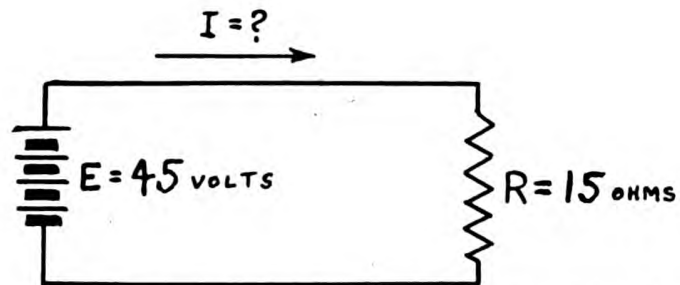


Figure 65. A simple circuit may consist of a resistor connected to a battery. Ohm's Law permits you to find the current when the voltage and resistance are known.

Now since the circuit is completed, electric current is flowing through the resistor. How much current is passing through the resistor? You may already know that current is measured in amperes, and so our question really asks, "How many amperes are passing through this circuit? How many amperes are supplied by the battery and pass around the circuit." In a later chapter we will learn that a meter can be used to measure this current, but now we will find out how the current can be found with the aid of a mathematical formula and the known facts about this circuit.

OHM'S LAW. In all direct current circuits (batteries supply D.C.) there is an important relationship between voltage, resistance, and current. Using the following symbols:

E = voltage in volts

R = resistance in ohms

I = current in amperes

Ohm's Law states that the voltage is equal to the product of current and resistance in the above units. Since this relationship is

very important in solving radio problems, we will state it mathematically in several ways:

$$E = I \times R \qquad I = \frac{E}{R} \qquad R = \frac{E}{I}$$

To use these formulas, first make certain that the known facts of the problem are expressed in the required units. If the resistance in a certain problem is expressed in megohms, change the value to ohms. Then use the formula which starts with the letter-symbol of the quantity you wish to find. Substitute in this formula the known facts as numbers in place of the other letters and solve.

In our earlier example, we were trying to find the current; then let us choose the formula which starts with the letter I. All units are already expressed correctly so no changes are needed. Substitute number 45 for E, and number 15 for R. Solve and you obtain the answer of 3. This means that the current is 3 amperes.

Please consider this additional example. A 1,000 ohm resistor is used in a certain radio circuit. It is known that the current passing through this resistor is 6 milliamperes. What is the voltage drop across this resistor?

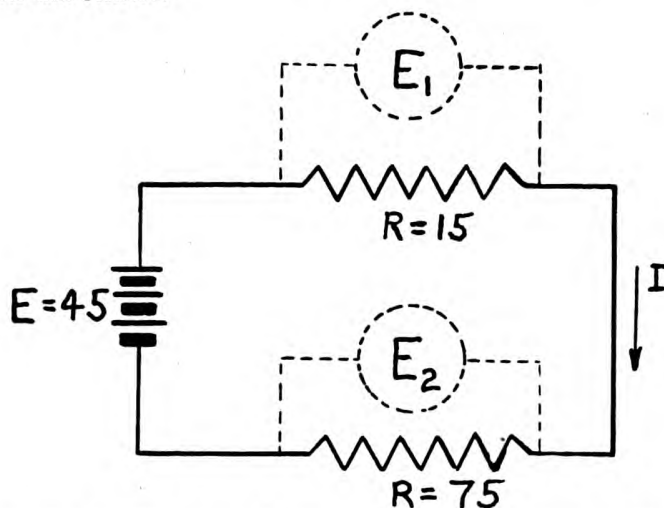


Figure 66. The voltage drops across the different elements making up the circuit, must equal the voltage supplied by the source (the battery in this case).

Here we are trying to find E and must use the formula which starts with this letter. Resistance is expressed in ohms, but the current is in milliamperes. Since each milliampere is one-thousandth part of an ampere, 6 milliamperes are .006 amperes, i.e. 6/1000 of an ampere. Now substitute in the formula. Multiplying the current of .006 by resistance of 1,000, we obtain an answer of 6 volts. That is the voltage drop across this resistor.

POWER. Besides being rated in ohms, every resistance possesses another electrical rating corresponding to its power handling ability or "wattage." The current flowing in a resistance, causing a definite voltage drop, results in a certain dissipation of power measured in watts and is equal to the current squared times the resistance. Symbol for watts is W.

$$W = I^2R$$

This is the most commonly used formula for wattage computation, although others made up of related factors are also used:

VOLTAGE DISTRIBUTION

The Ohm's Law relationship is so important and is so often used in practical radio work, that you must make certain you understand this material and are able to apply these formulas to simple problems.

Although the Ohm's Law stated is intended for direct current circuit only, it may also be applied to A.C. circuits (such as electric power supplied to most homes) if only resistive loads are considered. Electric bulbs behave very much as resistors. If a bulb is operated from 110 volts, and draws 0.2 amperes, the resistance of the bulb may be found from the Ohm's Law relationship. Using the expression where R stands alone on one side of the *equal* sign, we substitute the known values and obtain an answer of 550 ohms.

Electrical *power* converted to another form of power (energy) is measured in watts. An electric motor may use a definite quantity of electrical power in watts. This *power* will be changed to mechanical energy; i.e., power of mechanical type to drive some mechanical devices. Electrical power dissipated in heat is also measured in watts.

POWER CALCULATION

Since a fuse is a safety device, its purpose is entirely defeated if it is replaced by another fuse of too large capacity (which will not provide any safety factor for the particular circuit), or if the fuse is shorted out with a piece of wire or metal.

You should make up similar simple problems to get the needed practice in using the formulas for computing power dissipated in circuits having resistors.

$$W = I \times E \qquad W = \frac{E^2}{R}$$

Composition-type carbon resistors are rated from $\frac{1}{4}$ to 2 watts depending on their size. Wire-wound resistors begin with about 5 watt size and go up to very large sizes that are used in transmitting equipment.

FUSES. The electric wires carrying current heat up if the current increases beyond a safe value. If the wires are permitted to become too hot, the insulation may start burning. Certain faults in circuits may cause the current to increase beyond a safe value. As a safety precaution, fuses are inserted in all power circuits. A fuse is made of a special metal which will melt and break the circuit when the current becomes excessive, but not large enough to damage the actual wiring.

WATTAGE RATING. The power dissipated by the resistor is changed to heat; if the heat is excessive due to overloading the resistor by more than just the normal current flow, the heat so developed may injure the resistor element. The ratings given are for open air mounting and where there are no close parts that may be injured by the heat. In mounting resistors in a closed chassis adjacent to other easily harmed parts, it is best not to load the resistors more than 50% of their rated wattage.

EXAMPLES. If a resistor of 3 ohms, carries a current of 2 amperes, what is the wattage dissipated?

$$W = I^2 R = 2^2 \times 3 = 2 \times 2 \times 3 = 12 \text{ watts}$$

A biasing resistor causes a drop of 30 volts, with a current of 15 milliamperes (.015 amperes). What is the wattage of the resistor?

$$W = I \times E = .015 \times 30 = .45 \text{ watts}$$

In this case a half watt resistor would do, but it would be better to use a one watt unit. More examples will appear later.

MAXIMUM CURRENT. The question of what current is permissible once the wattage and resistance of a unit are known comes up quite often. The formula below, derived from the regular wattage formula, will enable us to do this.

$$I = \sqrt{\frac{W}{R}}$$

The following problem may be taken as an example. What current may a 2 watt, 800 ohm resistor carry as a maximum?

$$I = \sqrt{\frac{2}{800}} = \sqrt{\frac{1}{400}} = \frac{1}{20} = .05 \text{ amperes}$$

The table below may be used for this purpose. This table may also be used to determine what wattage to use with a certain resistor and current flowing through it. Usually this is the information known and, therefore, the table will be very handy. For example, if you are using a 10,000 ohm resistor and the current is 25 milliamperes (.025 amperes), then the wattage required will be greater than 5 watts, and therefore, a 10 watt unit should be used.

USING OHM'S LAW CHART

WATTS	$\frac{1}{2}$	1	5	10
Resistance	current I in amperes			
1	.707	1.000	2.236	3.163
2	.500	.707	1.580	2.236
5	.316	.447	1.000	1.414
10	.224	.316	.707	1.000
25	.141	.200	.446	.632
50	.100	.141	.316	.447
100	.071	.100	.224	.316
200	.050	.071	.158	.223
300	.041	.058	.129	.182
500	.032	.045	.100	.141
700	.027	.038	.085	.129
1,000	.022	.032	.071	.100
1,500	.018	.026	.058	.081
2,000	.016	.022	.050	.071
2,500	.014	.020	.045	.063
3,000	.013	.018	.041	.057
4,000	.011	.016	.035	.050
5,000	.010	.014	.032	.044
7,000	.008	.012	.027	.038
10,000	.007	.010	.022	.031
15,000	.006	.008	.018	.025
20,000	.005	.007	.016	.022
25,000	.004	.006	.014	.020
50,000	.003	.004	.010	.013
75,000	.003	.004	.008	.011
100,000	.002	.003	.007	.010
200,000	.002	.002	.005	.007
300,000	.001	.002	.004	.006
500,000	.001	.001	.003	.004

HOW TO USE THE OHM'S LAW CHART. The alignment chart, prepared by the Ohmite Mfg. Co., enables graphical solution of Ohm's Law problems. To use, place a ruler across any two known values on the chart; the points at which the ruler crosses the other scales will show the unknown values. The *italic* figures (on the left of the scales) cover one range of values and the roman figures cover another range. For a given problem, all values must be read EITHER in the *italic* numbers or in the roman numbers.

Example No. 1. The current through a 12.5 ohm resistor is 1.8 amperes. What is the voltage across it? The wattage? Answer: Dotted line No. 1 through R = 12.5 and I = 1.8 shows E to be 22.5 volts and W to be 40.5 watts.

Example No. 2. What is the maximum permissible current through a 10 watt resistor of 2,000 ohms? Answer: Dotted line No. 2, through W = 10 and R = 2,000, shows I to be 70 milliamperes.

RESISTOR CIRCUITS IN RADIO.* Please refer to the illustration (A) of Figure 68. Here we have a choke commonly used in a power supply of a radio set. We know that this choke has a resistance of 100 ohms, and that it produces a voltage drop of 50 volts. Applying the Ohm's Law statement, we can solve for the current, I.

$$I = \frac{E}{R} = \frac{50}{100} = .5 \text{ amperes}$$

*These examples were taken from: *Radio Service Encyclopedia*. Second Edition, 1938, published by P. R. Mallory & Co.

If you wish to use the table to find the maximum permissible current in amperes which can be safely handled by a given resistor, proceed as follows: Find the "ohm" value of resistor in the first column. Closest value in the table will serve. Proceed across from this value until you reach the column where the power of the resistor is stated at the top of the column. The value given in this column is your answer in amperes. For example, given a 5,000 ohm resistor. Find it in the first column. Proceed across. For one watt size (if this unit is one watt) find the proper column. Do you see the value, .014 amperes? This is maximum; of course, lower value current is permissible.

If the resistor and current are known, you can find what size (wattage) will be required. Find the "ohm" value of the resistor in the first column, and then travel across until you come to a current value which is first along the way from the left, but is larger than the given value of current. Look at the top of the column; the wattage of the resistor needed is given there.

This chart is on the next page. Obtain the needed practice by following the examples given and then working a few additional problems which you can make up yourself.

EXAMPLES IN USING THE CHART

The explanation for using this chart shown under Figure 67, is given on page 45.

These examples refer to the illustration shown in Figure 68, on page 47.

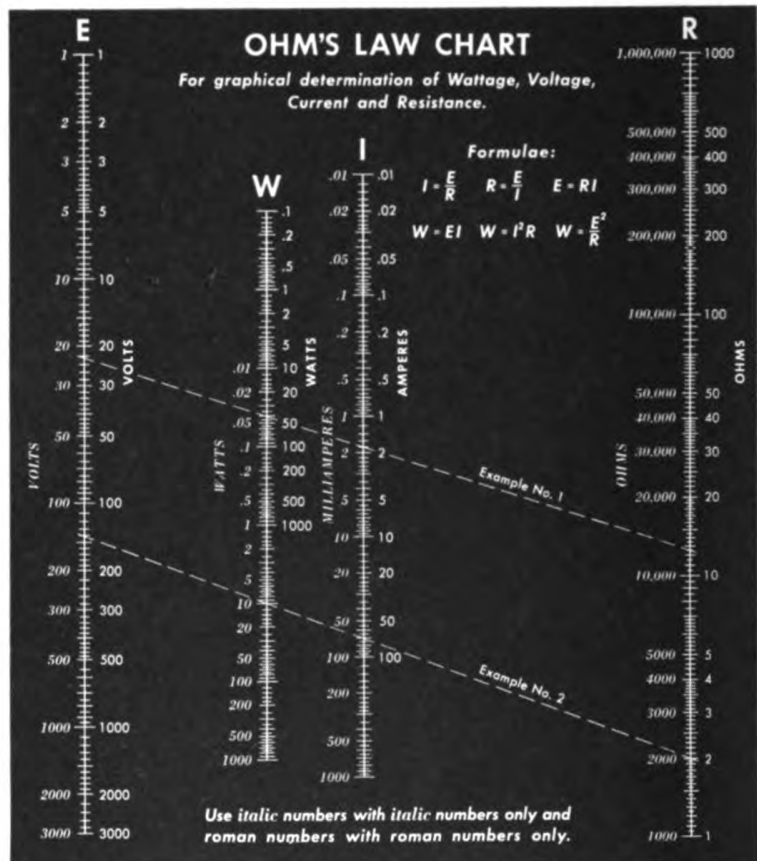


Figure 67. In practical radio work, approximate values are accurate enough. With the aid of this chart you can work most resistance problems.

In illustration (B) you will notice that the voltage from one side of the resistor to ground is 250 volts as indicated by the meter. From the other side of the resistor to ground the voltage is 300 volts. This indicates that 50 volt drop occurs across the resistor. The current, I , is .005 amperes, as indicated on another meter. We use another form of the Ohm's Law, to solve for R .

$$R = \frac{E}{I} = \frac{50}{.005} = 10,000 \text{ ohms}$$

In illustration (C) the current passing through the tube and indicated on the meter as .005 amperes, will also pass through the resistor wired in the cathode circuit. We know this resistor is 2,000 ohms. What will be the voltage drop across this resistor?

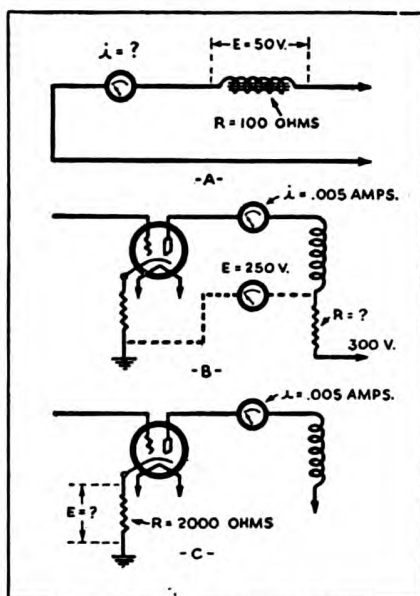
$$E = I \times R = .005 \times 2,000 = 10 \text{ volts}$$

In the figure above, we wish to know what power will be dissipated in the 2,000 ohm resistor. Using the formula below and making the needed substitutions, we obtain the answer.

$$W = I^2 R = .005 \times .005 \times 2,000 = .05 \text{ watts}$$

KIRCHHOFF'S LAWS. These laws constitute a further application of Ohm's Law to more complicated circuits. *Kirchhoff's First Law*

states: "Any current flowing to a point in any electrical circuit is equal to the sum of the currents flowing away from that point."



Reprinted from Mallory Radio Encyclopedia
Figure 68. Circuits illustrating fundamental calculations which require familiarity with Ohm's Law. (A) Solving for current flowing in a circuit; (B) the resistance which is needed to produce a given voltage drop; (C) the voltage drop produced by a given resistance.

Kirchhoff's Second Law states: "In any closed electrical circuit the sum of the impressed voltages will equal the sum of the voltage drops." The voltage drops must be in the same direction or they must be combined algebraically. We have already used this law, when we noticed that the sum of the drops in two series resistors equalled the battery voltage.

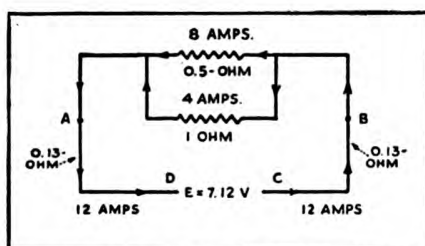


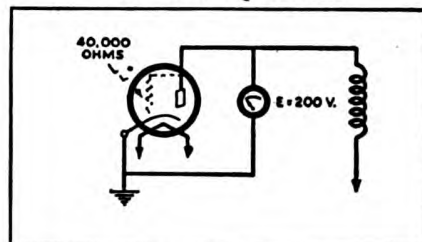
Figure 69. Illustration of Kirchhoff's First Law, "A current flowing into a circuit is equal to the current leaving the circuit."

In the figure, you will note that the sum of the currents, 8 amperes and 4 amperes, flowing towards point A, is equal to the current, 12 amperes leaving point A. This illustrates the First Law.

Kirchhoff's Second Law is also numerically illustrated in this figure. Assume that the resistance of the various parts of the circuit are as marked, and that the total internal resistance of the battery is .6 ohms. Then according to the statement of the Second

KIRCHHOFF'S LAWS

Additional Questions



Courtesy P. R. Mallory & Co.
Figure 71. A radio tube has its plate resistance equal to 40,000 ohms. Assume that the D.C. resistance equals plate resistance in this case, and that the tube will act as a resistor of this value. A voltage of 200 volts is applied to the plate. What current will pass through the tube?

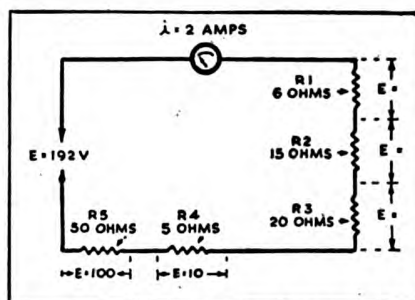


Figure 72. A circuit consists of five resistors connected to a battery as shown. The ammeter indicates that 2 amperes of current passes through the circuit. Find the voltage drops across each resistor. The total of all voltage drops should equal the battery voltage of 192 volts.

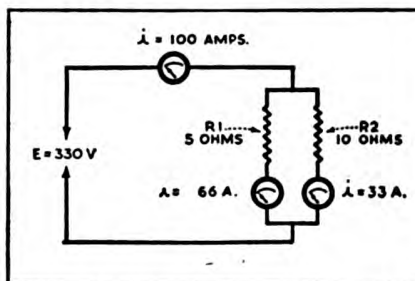


Figure 73. Check the values of current as indicated by the ammeters connected in the circuits. Do you agree with the results?

REVIEW QUESTIONS

1. Find the resistance per foot and then multiply by 17.

4. What is the resistance of a *pure* carbon resistor? Does this suggest the answer?

5. There are two right answers to the first part of the question. Remember the usual accuracy of resistors when answering the last part.

8. If you have a radio parts catalog, look up the prices of various wire-wound resistors.

10. Can you *invent* additional applications for potentiometers?

11. You may also make up similar problems, yourself.

The B— connection of the battery is made to the ground or chassis. Electrons may be considered starting from B—, pass through the cathode resistor, from the heated cathode inside the tube to the plate, through the plate meter, and back to the B+ of the battery. This action will be clearer when you study the behavior of vacuum tubes.

13. You can work this out from formulas or get the answers by using a suitable table for each case.

Law, if the impressed voltage is 7.12 volts: Impressed Voltage = sum of voltage drops in the circuit, or the drops will be, (C to B) $12 \times .13$, plus (B to A) only one branch needs to be considered since the voltage across the branches is the same, 4×1 (or 8×0.5), plus (A to D) $12 \times .13$ to complete the circuit. When you add up the results, you will find the answer will check with 7.12 volts.

REVIEW QUESTIONS AND PROBLEMS. 1. A piece of nichrome resistance wire six feet long has a resistance of 100 ohms. A piece 17 feet long of this same wire will have how many ohms resistance?

2. If another wire of twice the cross sectional area, also six feet long, is used how many ohms will it have?

3. From a practical point of view, does the resistance of a copper conductor change any when an insulation is placed on the wire? What if the wire is stretched?

4. Why do you think it is not practical to make carbon resistors in values less than 100 ohms? What do you use when you need a resistor of only 20 ohms?

5. How can a resistor be color coded to represent 70 ohms? Can you represent 175 ohms by means of the color code? Why is this question only of theoretical importance?

6. Does the physical size of a carbon resistor (length and thickness) tell you anything about the electrical resistance? Why?

7. What are the extreme values of a 200,000 ohm resistor only accurate to within plus or minus 20%?

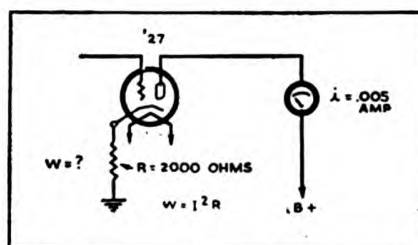
8. If a section of a wire-wound resistor with taps burns out, how can the repair be made most economically?

9. What are the main differences between rheostats and potentiometers?

10. Name two uses for potentiometers in home-type radio receivers?

11. Solve the combination circuit problem of this chapter (involving resistors in mixed circuit), but changing the values of the five resistors.

12. A 60 watt lamp connected to a 110 volt line uses how much current? What is the resistance of this lamp?



Courtesy P. R. Mallory & Co.

Figure 70. A cathode biasing resistor of 2,000 ohms is connected as shown. The plate current of .005 amperes must pass through this resistor. What power in watts is dissipated by this resistor?

13. A resistor used in a radio set causes a drop of $7\frac{1}{2}$ volts when a current of .005 amperes passes through it. What is the resistance? How many watts are handled by this resistor? What commercial size resistor can be used for this purpose?

14. How can an 800 ohm equivalent resistor be formed from several 600 ohm resistors which are the only ones available for the purpose?

LESSON 5

Properties of Coils and Transformers

MAGNETISM. Magnetic force is important for the operation of many radio component. Relays, transformers, and loudspeakers operate on the principle of magnetism. Being similar to electricity, we cannot actually see or feel magnetism, but the effects of this force can be noticed and accurately measured.

Natural magnets exist. If a piece of hard steel is stroked in the same direction with a piece of natural magnet, the steel will become permanently magnetized. For practical use, a small percentage of nickel, chromium, or cobalt is added to steel for making permanent magnets which have greater magnetic strength and other desirable properties.

Just as in the case of electrical charges,

**UNLIKE MAGNETIC POLES ATTRACT EACH OTHER,
LIKE MAGNETIC POLES REPEL EACH OTHER.**

Also it is important to remember that the force of attraction or repulsion between two magnets is inversely proportional to the square of the distance between the poles of the magnets. A north pole of one magnet will attract the south pole of another magnet four times as much at a 1 inch distance as at a 2 inch distance. This is the reason why the space between the moving coil and the fixed magnet of a loudspeaker is made so small.

If either end of a bar magnet is dipped in iron filings, most of the filings will stick to the pole, indicating that the attractive force is greatest at the poles. This magnetic effect is noticeable for a considerable distance around the magnet. This attractive force is the magnetic field. We speak of lines of force being present and connecting the two poles of a magnet. The filings around the magnet follow the lines of force.

If a strong magnet is dipped in a barrel of nails which are made of soft iron, many nails will stick to the magnet. Some nails, in turn, will hold other nails, becoming temporary magnets. However, once the nails are removed from the magnet, their magnetism is lost. Hardened steel substances, on the other hand, will retain some magnetism once they are brought into contact with a permanent magnet.

ELECTROMAGNETISM. Although many devices employed in radio circuits depend on permanent magnets for their operation, magnetism produced by the flow of electric current through a conductor finds even greater application. Every wire carrying electric current has an associated magnetic field proportional to the current strength and the arrangement of the wire.

The fact that an electric current in a conductor has an associated magnetic field may be proven easily. If a compass is held near the wire, the needle of the compass (actually a small magnet on a pivot) will take a position at right angles to the wire. If no current is present in the wire, the needle will assume its natural position pointing North.

If you are able to obtain two toy horse-shoe or bar magnets, we suggest that you observe their actions. Notice how the like poles repel each other. If iron filings are available, you may experiment further in observing the *lines of force* of the magnets. To do this, place a thin cardboard on the magnetic poles and sprinkle the filings on the cardboard.

A simple electromagnet may be made by winding a number of turns of wire on a large nail or spike. The beginning and end of the coil may be connected to the terminals of a small battery for a few minutes while you observe that this electromagnet behaves in exactly the same way as a similar fixed magnet. Notice also that no magnetic properties are present if the electric circuit is broken.

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ELECTROMAGNETIC PRINCIPLES

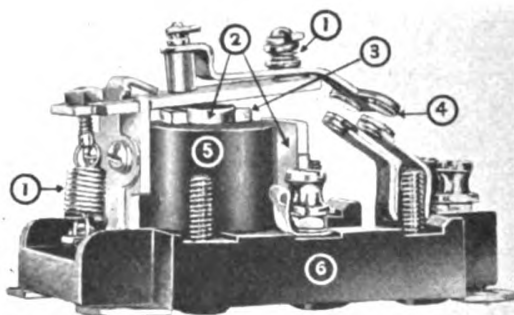
If you have constructed an electromagnet, you may further observe the change in the magnetic strength when the voltage of the battery is increased. Two or more batteries may be connected in series to increase the voltage supplied.

Relays are employed for a variety of electronic applications. As remote controls, they serve to release bombs, select telephone connections on dial telephone exchanges, and to warn operators concerning the improper operation of equipment. Relays are basic components of all equipment which employs photo-cells.

An electromagnet is made by winding a number of turns of wire in the form of a coil. A much stronger magnetic field can be created since the fields of all the individual turns will add up. Since the magnetic field of force of each turn adds to that of the next turn, the greater the number of turns of wire the coil has, the stronger will be the magnetic field.

The total magnetic flux (lines of force) depends on the number of turns and the current strength. If the current is strong, relatively few turns of thick wire will be needed to produce a given magnetic field. On the other hands, if the current is very minute a great many turns of fine wire will be needed.

If a bar of iron is placed in the center of the coil the iron will become magnetized when the current flows through the coil, but will lose its magnetism once the current is stopped. This principle is used to operate relays, door bells, and other devices.



Courtesy Struthers Dunn, Inc.

Figure 74. A detailed illustration of a radio relay.

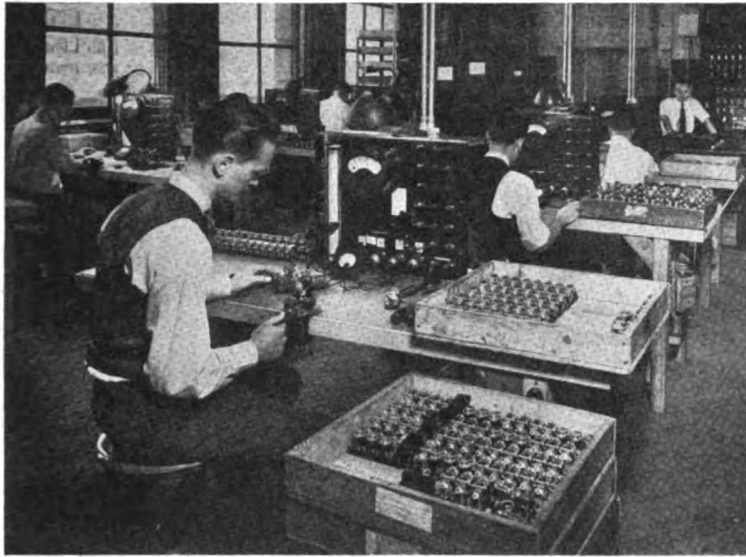
RELAYS. All relays use an electromagnet, see part marked 5, in the illustration. Near the magnet is a movable armature made of magnetic material. Normally, a small spring, number 1 part at the left, keeps the armature slightly away from the electromagnet. The core of the magnet is marked 2 and 3. When the coil carries the required amount of current, the armature moves down, and contact is made by terminals marked 4. This completes an outside circuit. By controlling the small current required for the operation of the electromagnet, it is possible to move the armature up and down, thereby closing or opening a different circuit which may be carrying larger current.

Relays are used for remote control, for safety as "fuses," for controlling segregated circuits, and for automatic operation.

MAGNETIC SATURATION. After a certain value, the increasing effect of the applied electric-magnetizing force will be diminished and, if the force is increased beyond a definite limit, no further increasing effect will be noticed. The substance being magnetized is then said to be saturated. For example, Wrought Iron will have a very strong flux when inserted in a copper wire coil rated at 10 ampere-turns. This rating means that the number of turns multiplied by the current in amperes must equal 10. Now if this arrangement is altered so that the magnetic force is 20 ampere-turns, the lines of force per square inch will be increased only to 97,000 from the previous figure of 89,000. At 40 ampere-turns this figure is only 106,000 lines per square inch. Saturation is reached when an

additional increase in ampere-turns has no further effect on the flux density measured in lines per square inch.

INDUCTANCE. All coils have an interesting property called inductance which is very useful in electricity and radio. It is easy to understand what this property does and we will explain these facts by describing an experiment which is historically important.



Courtesy Struthers Dunn, Inc.

Figure 75. Many interesting well paying positions in the Radio and Electronics fields will be opened to you after you complete your study of this course.

We have already learned that an electric current in a conductor sets up an associated magnetic field. The magnetic field will be stronger if the wire is made in the form of a coil. If this conductor (preferably in coil form) is moved across the magnetic field of a permanent magnet, a current or voltage will be noticed to exist in the circuit. The needle of the sensitive meter connected to the

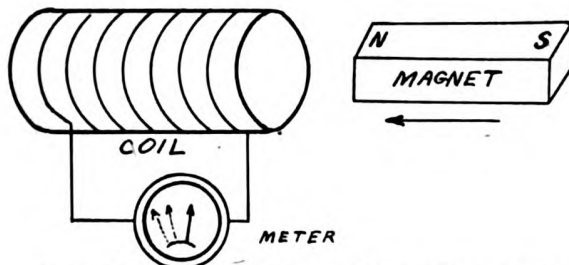


Figure 76. A conductor has a voltage induced when it cuts magnetic lines of force. The meter indicates the presence of voltage. Either the coil of wire or the magnet may be moved to produce the effects.

coil will indicate the existence of a voltage. If the coil remains fixed in relation to the magnet, no indication will be shown by the meter. As the direction of motion is altered, the needle will swing to the left and then to the right. This shows that the voltage generated by the motion is altering its direction.

EXPLANATION OF INDUCTANCE

You should realize that the conductor (copper wire of the coil) must *cut* the magnetic lines of force. This is possible if either object is in relative motion in respect to the other. Either the coil or the magnet may be moved to induce the voltage in the coil. Even both the coil and the magnet may be in motion, but they must not be moved in the same direction at the same rate. Later on, you will learn that by using an electro-magnet (instead of a fixed magnet), no motion will be needed provided the electric current used to excite the electro-magnet is of a changing (alternating) type.

MAGNETIC CIRCUITS

It is recommended that you memorize and be able to repeat at least in your own words this important relationship of electro-magnetic circuits.

You can see that the property of self-inductance makes the coil act as if it had higher *resistance*. This action will be explained in greater detail on page 56.

Please remember from this experiment that the voltage is present only when there is motion, that the intensity of voltage (meter movement) is proportional to the rate of motion, the number of turns in the coil, and the flux density of the magnet used. This principle of voltage generation is employed in all electric dynamos.

LENZ'S LAW. The effects observed in this experiment have been summarized and are known as Lenz's Law. We say that when there is any variation of a magnetic field with respect to a conductor, the voltage induced in the conductor is in such a direction as to produce a current which will tend to prevent the original variation. Work was done in our experiment since we had to overcome this tendency of the coil to prevent any change.

SELF-INDUCTANCE. We can use this interesting law to explain the tendency of an inductance (coil) to prevent a change in the current passing through it. If a coil is connected to a battery, at the first instant only a tiny current would pass, let us say, due to the passage of the very first few electrons. This current will create a small electromagnet which will act in the same way as a correspondingly small permanent magnet. Since the current is increasing, the flux is increasing and appears, to the turns of wire, as a moving magnetic field. But this action, by Lenz's Law, will tend to prevent any further change by producing a counter voltage. This is actually what happens and a short time passes before the current rises to a maximum value. But if the same wire was strung out and connected to the battery, the maximum current would occur almost instantly.

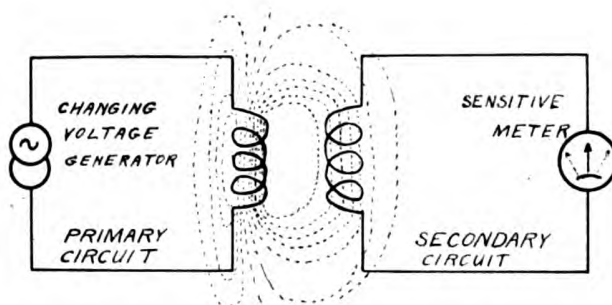


Figure 77. A varying current flowing in the primary circuit, produces a varying magnetic field which induces a voltage in the secondary circuit. This is the principle of the transformer.

TRANSFORMER ACTION. It is also possible to induce a current in one conducting circuit by means of the changing magnetic field produced by the current flowing in another associated circuit, which is not electrically connected to the first circuit. The flux set up by the first circuit induces a current in the second circuit. This action takes place only while the current in the first circuit is changing (increasing or decreasing) as in the case when the first circuit is connected to a source of current that is periodically rising and falling. The circuits must be located closely together, that is coupled together. A device used to transform electrical energy by induction is called a *transformer*. A transformer does not create energy, it simply separates two circuits, and steps the voltage up or down. When any voltage is stepped up by means of a transformer, the current correspondingly in the same ratio is stepped down.

TRANSFORMER. The coil receiving the original current is called the primary, and the coil in which the current is induced by electromagnetic induction is called the secondary. In the illustration it is evident that since only a part of the lines of force set up by the primary link the secondary coil, the current induced is not as great as would be in case all the lines of force linked the secondary. The lines of force not linking the secondary and, therefore, not being useful are termed the leakage flux. To keep the lines of force in the desired path soft steel material is used for the core. Usually thin sheet laminations are employed to reduce losses.



Figure 78. Transformers used with low (power or audio) frequencies have iron cores. The illustration shows an upright type power transformer used in radio sets. Wire leads come out of the bottom. The transformer is bolted to the chassis and the wire leads go through an opening in the chassis.

Transformers and inductors having air cores are used in radio receiving circuits where the frequencies encountered are very high and would create heavy losses due to *eddy* currents and *hysteresis* if iron cores were used. Where the frequencies are relatively low, as in the case of audio (sound) frequencies and power frequency of 60 cycles, iron laminated cores are used.



Figure 79. The antenna coil illustrated is a transformer used for radio frequencies. An air core is used and the wire is wound on insulated tubing. Connections are made to lugs.

UNIT OF INDUCTANCE. The unit of inductance is the *Henry*. A coil has an inductance of one henry if a current change of one ampere per second will produce one volt pressure in the coil. The letter *L* is used as the symbol for inductance.

The henry is a relatively large unit and while some audio coils having special iron cores have an inductance of several hundred henries, the inductance encountered in coils used in radio frequency work and having air cores is only a small fraction of a henry. One thousandth of a henry is a millihenry, and one millionth part of a henry is called a microhenry. Coils used for tuning the broadcast frequencies are in the order of 220 microhenries.

Inductive coils may be connected in series, in parallel, and in other combinations *without* the magnetic fields interlinking to any degree. When inductors are connected in series, under these conditions, the total effective inductance is the sum total of the individual inductances.

MUTUAL INDUCTANCE. If two coils are connected in series and do have their magnetic fields interlinking, the total inductance for the two coils may be greater or less than the sum of the individual inductances. The reason for this is easy to explain. If one coil's magnetic field links the second coil, the turns of this second coil may be considered as adding to the turns of the first coil. Now it is obvious that the inductance increases with the number of turns,

MORE ABOUT INDUCTANCE

The primary coil which carries the *exciting* current in the transformer produces the magnetic field and this field, which must be of a changing type, may link one or more secondary coils. Iron cores concentrate the magnetic field. In air coils, only a small percentage of the total lines of force links the secondary coils.

If two coils are separated by a distance of several feet or are shielded with metal cans, they may be assumed not to have their magnetic fields interlinking.



Wire-wound resistors, using cylindrical cores, have considerable self-inductance which is not permissible in some circuits. If the resistance wire is wound in a special way on flat strips, the units will have almost no inductance.

The coefficient of coupling in iron core transformers is almost equal to 1. In radio air core coils, the coefficient of coupling is very small, around 0.05.

and the coil will have an *apparent* higher inductance. This same reasoning will apply to the second coil inductance in relation to the first coil.

We have assumed that the turns of one coil were equivalent to the turns added to the second coil. This, of course, requires that both coils have the turns wound in the same direction and be placed in a position to have the magnetic fields attract each other. If this process is reversed, as when the turns are wound in the opposite direction, or the magnetic fields buck each other, then the second coil will act to "subtract" the effect of some turns on the first coil. Less turns on the coil will reduce the effective inductance. Coils which are spaced a great distance apart, or are separated with metal shields, or are at right angles to each other, have very little effect on each other.

The change of the inductance value of a coil, because of the action described, is really equal to another coil being connected in series. It is as if this imaginary coil had a definite value of inductance which was added or subtracted from the inductance of the real coil. This additional inductance which must be considered in practical circuits is known as mutual inductance.

COEFFICIENT OF COUPLING. When two coils are arranged so that some definite mutual inductance exists, the coils are said to be magnetically coupled. In many practical calculations, as you will see later, it is more convenient at times to express the amount of coupling as a fraction of the maximum coupling possible rather than the numerical value of mutual inductance. If the fields of two coils are almost in common, the coefficient of coupling approaches 1, but if the coils are segregated the coupling coefficient becomes zero. Mathematically, the coefficient of coupling, k , may be expressed in terms of the mutual inductance M , and the self-inductance of the coils, L_1 and L_2 .

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

GENERATORS. Electric power is produced in the power stations with aid of dynamos. Although dynamos are complex machines they depend on a very simple principle familiar to us. Conductors cut across a magnetic field and have a voltage induced. As only one conductor cuts across the poles of a magnet, it may at one time move almost parallel to the lines of force and, at that instant, produce no voltage in the output of the machine. An instant later, in revolving in the magnetic field, this same conductor begins to cut across a few magnetic lines, but it is still moving somewhat parallel to the lines of force. The voltage in the output is increasing. As the conductor cuts through the center of the magnetic lines and at right angles to these lines, the output voltage is maximum. After this the voltage begins to diminish and finally drops to zero again.

Now the conductor begins to revolve closer to the other pole, and the voltage will rise and fall again as before, but in the opposite polarity. Although dynamos have large coils instead of a single conductor, and many pole pieces, the voltage generated has this characteristic of starting at zero, rising to a maximum, dropping to zero, rising to a maximum in the opposite direction, and then returning to the original position. This type of voltage is alternating in character.

SINE WAVE. In our discussion of batteries, we talked about direct current, D.C. This current is either of a constant or varying value but flows in one direction all the time. One terminal in a D.C. circuit is always positive, the other terminal is always negative. When the magnitude of D.C. changes, we call this pulsating direct current. Alternating current (A.C.) has a constantly changing magnitude and periodically changing direction. In an A.C. generator, first one terminal is positive, and the voltage is rising, see

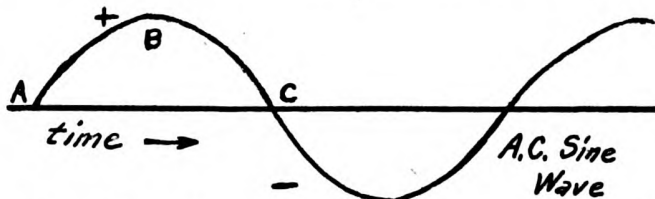
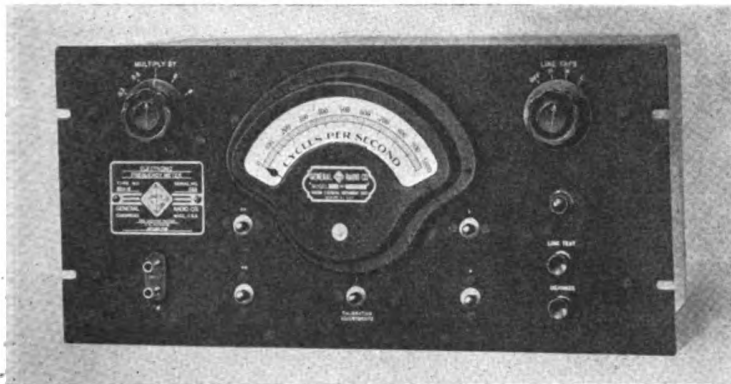


Figure 80. A sine wave is important in the study of radio principles. Certain generators produce sine waves. Since any wave, no matter how complex, can be resolved into the sum of sine waves, this function is basic in our study.

chart, part A to B. Then the value of voltage begins to fall, but the same terminals remain positive and negative, see B to C. At C the voltage present is zero, and then it begins to rise in the opposite direction. The process described in this paragraph is repeated but the terminal voltage is reversed. The usual generators of A.C. produce sine waves of the type illustrated.



Courtesy General Radio Co.

Figure 81. Special units can be constructed to indicate the frequency directly in cycles. The fact that most power line frequencies are exactly 60 cycles, permits electric clocks to keep accurate time.

CYCLE. After the voltage has started from zero, has risen to its maximum value in one direction, returned to zero, risen to the maximum value in the opposite direction, and then returned to zero, one complete cycle has been completed. You should draw a sine wave of several cycles, and mark off the cycles. The number of cycles present per second determines the frequency. The common power line frequency is 60 cycles per second; this means that sixty such changes occur every second. This explains why in dealing with A.C., time must be considered.

PERIOD. The amount of time needed for one cycle to be completed is known as the period. If the number of cycles per second

SINE WAVE GENERATION

It is easier to generate A.C. with electric dynamos. Further, A.C. produces a changing magnetic field in transformers and permits the voltage to be stepped up or down as may be required.

In every cycle, there are two minimum values of voltage and two maximum values of voltage — the maximum values being of opposite intensity.

The information and numerical factors given apply to sine waves. Sometimes, A.C. wave has characteristics very far removed from a pure sine wave and, in such instances, the effective and maximum values are related in a different manner.

is known, then the period can be found by dividing one by this number. For example, the period of 60 cycle current is: $1/60$ or one-sixtieth part of a second.

Usually one cycle is produced by rotating machinery when a conductor sweeps all the way around, that is completes a circle. We know that a circle has 360° . This permits us to divide the space taken by a sine-wave single cycle into 360° . In radians,* 180° is equal to the Greek letter π , and fractions of π are used at times to represent division points. Notice that if a voltage, in the form of a sine wave, has zero value at 0° , then it has a maximum at 90° , zero value again at 180° , and another maximum at 270° . The wave is the same at 0° and 360° .

EFFECTIVE VALUE. At different parts of the cycle, the A.C. voltage is equal numerically, without reference to the positive-negative terminals, to some value between zero and maximum voltage. The instantaneous voltage is changing all the time. The value of this varying voltage as indicated by the usual A.C. voltmeter is the root-mean-square, RMS, value. The RMS value is equal to .707 of the maximum value. If in a circuit the peak (highest, maximum, greatest) voltage is 100 volts, then the RMS value indicated by a meter will be 70.7 volts. The RMS value is also called *effective* value since a D.C. voltage of this same value would cause as much heat in a resistor as this A.C. voltage. The house power circuits of 110 volts A.C. really means 110 volts RMS or effective, and an electric iron will give the same heat from this voltage as from 110 volts D.C.

In application, it is sometimes important to know the maximum or peak value of A.C. voltage when the RMS only is measured. The maximum voltage is equal to the RMS value multiplied by 1.4 approximately. From this we see that the maximum A.C. voltage or current is about $1\frac{1}{2}$ times the RMS value as indicated on a meter.

INDUCTIVE REACTANCE. We have already learned that an inductance tends to prevent any changes in current intensity. If a circuit containing an inductance (coil) is connected to a source of D.C., such as a battery, a short time will be required for the current to rise to its steady maximum value. This is because the current starts from zero at the instant the circuit is completed, and the inductance will oppose a sudden change to the maximum value.

Now consider the same inductance being connected to a source of 60 cycle A.C. Let us complete the circuit at the very instant the voltage is zero and is just starting to rise. The current will have to change from zero to some maximum value in relation to the voltage, but will be reduced in value because it will always lag behind the value it would have if the inductance were not present. The inductance will make the value of current lag and when the current reaches a value, still considerably under the maximum it would be with a corresponding D.C. voltage, the A.C. voltage will drop back to zero. The current, therefore, will never reach the maximum value it had with D.C., and it seems that an inductance has a sort of special opposition to alternating current.

The more times per second the voltage drops to zero, the less chance the current will have to rise and will remain at lower values. We can see from this that the higher the frequency (greater number

*The angle sustained by an arc of a circle which has its length equal to the radius, is equal to one radian.

of cycles per second) the greater will be this special inductive opposition. This action of an inductance to limit current in an A.C. circuit is known as inductive reactance. Inductive reactance is very similar to resistance, but is different for various frequencies, and increases with the frequency. Inductive reactance is also measured in ohms.

The symbol for reactance is letter X. For inductive reactance we use the special symbol, X_L . Inductive reactance can be calculated from a very simple formula:

$$X_L = 6.28 \times f \times L$$

The constant 6.28 is really equal to 2π , f is the frequency in cycles per second, and L is the inductance in henries.

Let us work a simple problem. A choke of 10 henries is used in a power supply to filter 60 cycle hum. We use the above formula and make the needed substitution.

$$X_L = 6.28 \times 60 \times 10 = 3,768 \text{ ohms}$$

This means that the 10 henries choke will have opposition to 60 cycle hum, the equivalent of 3,768 ohm resistor. But while a resistor will also have this same opposition to the D.C., the choke will have negligible resistance (reactance) to direct current.

RADIO COILS. Radio receivers and transmitters use radio coils with air cores. These coils are made from various sizes of copper wire, and are wound on insulated tubing varying in diameter from $\frac{1}{2}$ to $1\frac{1}{2}$ inches in modern receivers and from $1\frac{1}{4}$ to 4 inches in small transmitters. We will now study these coils.



Courtesy Meissner Mfg. Co.

Figure 82. To prevent inductive coupling, radio coils are usually shielded in metal cans. Notice that the coil is supported with a bracket to the wall of the shield. Connecting terminals are at the bottom.

Most radio receiver coils, used in the radio frequency sections, consist of a primary and secondary. These coils are wound in a special manner to reduce capacity effects. The primary usually occupies less space and sometimes is a separate small coil mounted



Figure 83. An inside view of an I.F. transformer. The primary and secondary coils are mounted on a wood doll-rod, and are spaced apart. The two trimmer condensers are mounted at the top of the shield.

Courtesy Meissner Mfg. Co.

within the coil form. These coils ordinarily are wound on one inch varnished or waxed cardboard tubes. The coils are mounted with the aid of metal brackets, or are attached to metal shields which support the coil and provide spade lugs for mounting the

After understanding the reason for inductive reactance, you should make up a few problems involving coils and frequencies of various values and solving these conditions for the resulting inductive reactance.

Recalling that the secondary of a R.F. coil has about 220 microhenries, calculate the inductive reactance of this coil at a frequency of 1,000,000 cycles. Assume that there is no condenser in the circuit. One million cycles corresponds to the frequency of 1,000 KC.

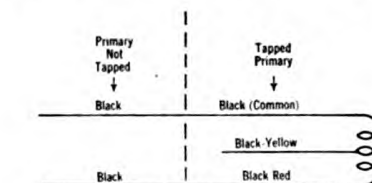
I.F. TRANSFORMERS

The color code for the power transformer indicates the variety of windings with center taps. Of course, the transformer may have fewer windings and may not have some of the center taps.

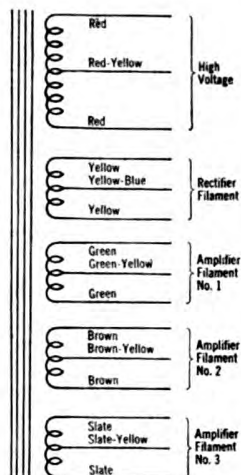
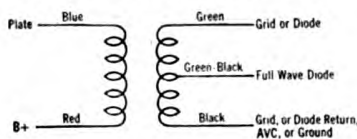
entire assembly. Small terminal lugs are rivetted to the bottom of the tubing and the wires of the coils terminate there.

Intermediate transformers (I.F.) are almost always shielded. The coils are small, identical, and are separated on the supporting core made of wood doll-rod. See the illustration. The four leads may

POWER TRANSFORMER LEADS



I F TRANSFORMER LEADS



Courtesy Allied Radio Corp.

Figure 84. The majority of commercial power transformer and I. F. coil wire leads are color-coded according to the scheme indicated.

come out of the bottom of the shield-can, or the grid lead may come out through the top of the can. Most I.F. transformers are correctly color coded:

Grid connection.....green wire
Plate connection.....blue wire
B+ voltage.....red wire
AVC or ground.....black wire

Small trimmer condensers are enclosed in the can. These condensers are mounted at the top and the adjustment screws can be reached through the openings at the top. These adjustments are used for alignment of the radio.

In superhet sets oscillator coils are used. These are made in a variety of styles to fit the circuit used, but usually the oscillator coils are small, unshielded, wound on 1/2 inch doll-rod, and appear to have a single inductance. However, there are usually two coils wound on top of each other, with leads going to four terminals.



Figure 85. A multi-band coil combines several coils in a single shield. Small trimmer condensers for each band are also included in the shield. In some radio sets, each coil is individually shielded and the trimmers are placed outside of the shield.

Courtesy Meissner Mfg. Co.

You will learn that because of inductive effects, radio frequencies (currents) travel on the outside of the conductor. This phenomenon is known as *skin effect*. This explains why some transmitter coils are wound with hollow copper tubing.

Transmitter coils are wound on ceramic forms, using thicker wire (No. 14 or heavier), and having means for changing the entire coil or tapping a section of the coil. These coils will be discussed in greater detail in the section dealing with Class C amplifiers.

LOSSES IN COILS. Certain losses are due to the resistance of the copper wire. Using thicker wire eliminates this to a large extent. However, at radio frequencies the effective R.F. resistance of wire is many times greater than the D.C. resistance given in tables or measured with an ordinary instrument. This effect is due to the movement of R.F. current on the surface of the wire only. Since only the surface is being used, the cross sectional area is greatly reduced. Actually for R.F. work, the center of the wire may be left out without increasing the R.F. resistance of the wire. When many fine conductors are used to form a cable for winding the coil, a larger surface area is possible for a given quantity of copper. Litz (Litzendraht) wire is of this type.

Eddy current losses occur in the shield if used. This fault can be minimized by using a large shield and one made of a good conductor. Copper or aluminum are best. Magnetic materials produce very high R.F. losses.

Dielectric losses are due to the material used for the tubing, wire insulation, and terminal strips. Because of economy factors not much attention is paid to these last items.

POSSIBLE FAULTS. Coils may open and, thereby, prevent the completeness of the circuit. A test with an ohmmeter, as described in Lesson 19, is applied. Turns sometimes short and sensitive signal tracing equipment must be used to detect this fault. In new equipment, coils may be connected incorrectly. Commercial coils are supplied with terminal connecting charts. The standard color code for I.F. transformers has already been stated. For antenna and R.F. coils the location of the terminals is an easy matter. In both cases, the top end of the large coil, which is the secondary, comes down through the inside of the tube to the grid-connection terminal. This connection usually leads to the control grid of the next stage tube. The other end of the secondary coil goes to the ground or AVC if used. One of the terminals of the primary coil will have an extra wire connected to it. This wire will run up along the coil and make a loop or two at the top of the coil. This loop is known as a gimmick and serves as a small condenser in the order of 3 to 10 mmfd. This terminal is for the antenna connection in antenna coils, or for the plate connection in R.F. coils. The remaining terminal of the primary is connected to the ground (chassis) in the case of antenna coils, and to positive voltage (B+) in the case of R.F. coils.

IRON-CORES. It is possible to obtain somewhat higher gain from radio coils by using a core made of special powdered-iron. The same value of inductance can be obtained with less copper wire which means less losses. Smaller losses give higher gain for the coil. You will find many commercial I.F. transformers using iron-cores, but some antenna and R.F. coils also use special core materials.

CALCULATING INDUCTANCE. Most radio coils are commercially made for specific applications, but at times you will be called upon to make your own coil or alter the inductance of a coil to a lower or higher value. It is helpful in such cases, to be able to calculate the number of turns needed. A great deal of time can be saved over the trial and error method of trying various number of turns. For these tasks, the diameter of the core and the wire size are usually known. If the number of turns is also known, then the inductance can be found. The table on the next page will permit you to do this work easily.

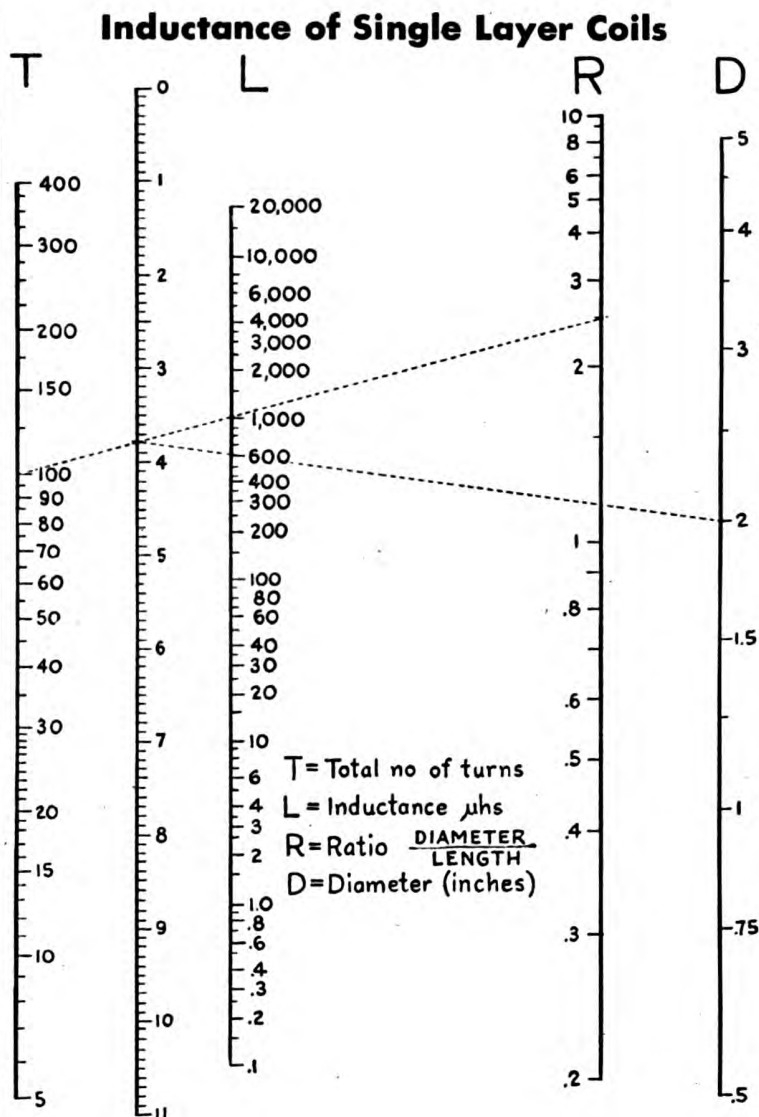
No special precautions are taken to prevent normal losses in coils. The reason for this is due to the simplicity with which the required gain can be obtained with modern vacuum tubes to make up for the losses encountered in coils.

It is not very common that faults develop in radio coils.

The example and the use of the chart given in Figure 86, is described on the next page.

FIGURING INDUCTANCE

You may be called upon to make a radio coil on a certain frame, using copper wire of a definite size, and to have the required inductance. This chart will permit you to know ahead of time how many turns will be needed. To carry out this work, place a ruler from the value of the diameter in inches, as shown in D column, to the inductance value in the L column. Notice where the rule intersects the column marked 0-11. Now move the ruler so that it *rides* on the point intersected on the 0-11 column. Guess at the number of turns and from a wire table of diameters, calculate the length of the winding. Now obtain the ratio of *diameter* of the coil-form to this *length* of wire. This should agree with the ruler intersection in column R. If it does not, shift the ruler so that a new value for the number of turns resulting in column T, and test once again. After several trials, you will come very close to the exact value.



Courtesy P. R. Mallory & Co.

Figure 86. Knowing the turns of a coil, the length of winding space, and the diameter, the inductance may be found. Place ruler on value indicating turns in T column (100 in example). Rotate ruler until it meets ratio (diameter $\div$ length) in R column, $2\frac{1}{2}$ in example. Place second line from the intersection of 0-11 numbered line to diameter; 3.8 to 2, in D column in our example. The answer in uhy. is 600 for the example, see column L.

FILTER CHOKES. A coil with a laminated iron core is used in power supply circuits. The iron core greatly increases the inductance of the coil. This arrangement opposes changes in current and, thereby, reduces the A.C. ripple, but has almost no effect on the direct current which serves the radio. Since this coil actually "filters" the power supply, or "chokes" out the ripple which may cause hum in the output, we call this coil the filter choke.

Filter chokes are rated in henries, and have values between 5 and 30. However, these values usually indicate inductance without a load; that is, with no current passing through the choke. When a

heavy current does pass through, as it must in an actual application, the inductance is greatly reduced. Most inexpensive chokes have an inductance of only one or two henries when used in actual circuits. Chokes are also rated in terms of the maximum current they may pass. A choke, of course, may be used in a circuit where the current is less than this maximum, but to overpass this value invites trouble and may cause the insulation to start burning. At times, the value of the D.C. resistance of the wire used in winding the choke is also stated. Always try to use a choke of proper inductance, but with as low as possible D.C. resistance value. The D.C. resistance causes losses to occur in the choke coil.



Courtesy Standard Transformer Corp.

Figure 87. Power transformers, of course, can be made in large sizes for radio transmitters. The principle of operation for all transformers is the same.

IRON CORE TRANSFORMERS. By placing the primary and the secondary coils of a transformer upon an iron core (laminated), it is possible to have almost all the magnetic lines set up by the primary inter-link the secondary coil. The transformers take different shapes; sometimes the coils are separated on different legs of a square shaped iron core, but more often modern transformers have one coil wound directly on top of another and placed on the center leg of an "E" shaped pile of laminations. Just think of a pile of such E laminations with the wound coils slipped over the center leg, and a pile of I-shaped laminations placed along side to complete the magnetic path. At times, the E laminations are inserted, a few from either side, to make a magnetic path with less air gaps.

Transformers and chokes using iron cores are used for power frequencies (25 and 60 cycles) and for audio frequencies (30 to about 10,000 cycles), for radio frequencies, we have already explained, air core coils are employed.

If a transformer has its primary coil connected to a source of A.C., the voltage will divide itself among the turns. For example, if we are working with 110 volts, and the primary has exactly

IRON CORE TRANSFORMERS

This reduction of inductance (in the choke) with the increase of current is not permissible in some circuits. Special *swinging* chokes are used in such cases. These chokes have a large gap in the iron core and have lower initial inductance under no load condition. However, with an increasing load, saturation does not occur to any large degree and the inductance remains more constant with changing currents and their corresponding changing magnetic fields.

TRANSFORMER CALCULATION

The diameter of the turns of a secondary winding of a transformer is of no practical importance; the number of turns determine the voltage induced. In most radio transformers, the primary is placed next to the core, then comes a high voltage secondary, then several filament voltage secondaries. The diameter of filament secondary coils may be twice as large as the primary coil diameter which is next to the core.

Certain engineering design practice calls for a certain needed minimum of turns for the primary of any useful transformer. Many beginner students, however, imagine that a transformer could be constructed with a sufficient number of turns on the secondary to give a billion volts. There are two limiting factors to dwarf these plans. As the number of secondary turns is increased, the coil becomes very large, and fewer lines of the magnetic field link all the turns of the secondary as is required for best results. Also, when very high voltage exists between nearby wires, the insulation will be broken down and a short will occur between turns. To use very heavy insulation on the wires would require an even larger coil and will not do for the first reason given.

330 turns, we will have 3 turns per volt, or each turn will have a drop of $1/3$ of a volt. Since the very same number of magnetic lines will link the secondary turns (we are assuming the transformer is perfect, it is nearly so in practice), each turn of the secondary will also have a $1/3$ of a volt. Now if the secondary also had 330 turns, you would measure 110 volts also across its connecting terminals. But if it had 660 turns, then you would obtain $660 \times 1/3$, or 220 volts. Or if the secondary had but 15 turns, you would have $15 \times 1/3$, or 5 volts. You can see that a transformer can be used to step voltage up or down.

You really do not gain anything with a transformer. The amount of power taken by the secondary, ($W = I \times E$), is the power delivered to the primary. In other words, if the voltage is greater in the secondary, the current is greater in the primary in the same proportion. Besides, every practical transformer has some additional losses in the unit itself.



Courtesy General Radio Co.

Figure 88. As you can see from the terminal panel of this Variac type transformer, the tap of the auto-transformer can be changed by rotating the handle and any voltage from zero to maximum can be obtained. The efficiency of a Variac is almost the same for all settings.

URNS RATIO. The turns ratio is the number obtained by dividing the number of turns of the secondary, N_s , by the number of turns of the primary, N_p . It is also the voltage ratio of the secondary, E_s , to the voltage of the primary, E_p .

$$\text{Turns Ratio} = \frac{N_s}{N_p} = \frac{E_s}{E_p}$$

AUTO-TRANSFORMER. The primary and secondary of a transformer need not be entirely separate. The entire winding, for example, may be used as the primary and only a fraction of all

turns used as the secondary. The same calculations will apply. However, the actual wire must be of the correct size to carry the maximum current of the circuit. In case some of the turns are used for both the primary and secondary, the wire of those turns must be able to carry the currents of both circuits.

TRANSFORMER LOSSES. We have already mentioned that practical transformers are not perfect machines. There is some copper wire resistance in the primary and secondary and this causes a voltage drop and a loss of power. A small percentage of magnetic lines produced by the primary may not actually link the secondary turns. The iron core itself acts as a conductor and has currents induced in it. These currents, of course, also represent a loss. A small radio power transformer may have an input power of 60 watts, but produce only 40 watts of useful power. Such a transformer is

$$\frac{40}{60} \times 100 = 66.7\% \text{ efficient}$$

Most of the larger commercial power transformers are 90% efficient. Efficiency is always equal to the output divided by input; multiplied by 100 to obtain the answer in percentages.



Figure 89. A half-shell power transformer may be supplied with connecting lugs at the bottom, or connecting leads may be used, as in the model illustrated.

RADIO POWER TRANSFORMERS. A transformer may have more than one secondary. Radio transformers usually have several separate secondaries. One of these secondaries supplies 5 volts (in most sets) for the rectifier tube filament. Other low voltages are supplied by other secondaries for the balance of the tubes used. A high voltage (total about 700 volts in most sets) is obtained from another secondary winding. This high voltage secondary is center-tapped, i.e. a connection is made to the exact electrical center of the winding. The different secondaries are insulated from each other and from the primary winding. A 60 cycle transformer has the core laminations piled to a certain thickness. A transformer designed for 25 cycle operation usually has the laminations stacked to twice the height. A 25 cycle transformer may be used for 60 cycle operation, but do not use a 60 cycle transformer for 25 cycle operation.

Power transformers may be of the upright type and require bolting to the chassis. These transformers have color coded wire leads.

Efficiency of any machine (a transformer is an electrical machine) is measured by dividing the output (useful) power by the input power. The result is a fraction less than one. The answer may be obtained in percent, by multiplying this fraction by 100.

A power transformer will have its primary *burn-out* if it is connected to D.C. source of corresponding voltage. This is due to very little D.C. resistance present in the winding, and the inductive reactance not *resulting* with D.C., that is, with current of zero frequency. With very little electrical opposition present, excessive currents will flow and overheat the copper wire of the coil.

RADIO AUDIO TRANSFORMERS

Audio transformers are used with a band of frequencies instead of with a single frequency as in the case of power transformers. Even the best audio transformer will have changing characteristics to various frequencies and the unit will not perform equally well for all frequencies of the audio band. Usually, at low frequencies (under 200 cycles), the inductive reactance is low and the gain of the unit (as used with a vacuum tube) is far down. The gain increases as the frequency rises, fluctuates a little with changes in frequency, and reaches a peak at some frequency between 3,500 and 6,000 cycles. There is a sharp drop in gain after this frequency because of capacity effects present in the transformer. But as the frequency is further increased, there may be another peak after 10,000 cycles.

Or these transformers may be of the half-shell type, mounted over a rectangular cut out in the chassis, and usually have numbered terminals for connections.

AUDIO TRANSFORMERS. We have already learned that transformers can be employed to change voltage and to separate electrically two circuits connected to the primary and secondary. Transformers can be used also to match circuits together. In such instances, transformers act very much as gears in an automobile used to match the speed of the motor to the required load. In accomplishing this electrical matching, transformers may also isolate two circuits and step the voltage up or down. In fact, transformers actually perform these three things together, but they may be used only to accomplish one or more of these things in a particular circuit.



Courtesy Standard Transformer Corp.

Figure 90. Good quality audio transformers may be similar in appearance to power transformers. However, the core material is of better quality and the windings employ much finer wire.

Audio transformers are physically smaller than power unit types, and they use better quality laminations to give better characteristics and have lower losses. Transformers may be used to match the loudspeaker to the output tube and are called output transformers when employed for this purpose. Audio transformers are also employed to couple audio stages. Here they not only serve as a match, but also isolate the circuits and give additional gain because of voltage amplification (step up).

REVIEW QUESTIONS AND PROBLEMS. 1. Name several radio parts which depend on magnetism for operation.

2. Explain how you could make a simple electromagnet.

3. If an electromagnet is made with an air core, and then an iron core is inserted, will the magnet become stronger? Explain your answer.

4. One electromagnet has 700 turns, and is passing $\frac{1}{2}$ ampere, another magnet has but 70 turns with a current of 10 amperes. Which electromagnet is stronger under the conditions given?

5. Make a sketch to show how a single relay can be used to control two separate circuits, closing one while opening the second. You understand that a relay may have more than a single armature and contact points.

6. Explain magnetic saturation in your own words.

1. Notice if any of these parts use iron.
2. Is iron needed for this construction?
3. What shaped iron will make this electromagnet the strongest?
4. The product of the turns by the current in amperes gives the comparative strength of an electromagnet.

7. Does a straight piece of hook-up wire have inductance?

8. Will you be doing actual work in moving a shorted turn of wire past a magnet? Explain your answer.

9. Make a sketch showing two coils with mutual inductance. Also make another sketch, showing the coils close together, but possessing almost no mutual inductance.

10. Make a drawing of a sine wave. Label the degrees on the base line. Make a mark for every 45° . Where are the maximums and the minimums? If you left the base line alone, but moved the actual curve so that its zero starting point is at 90° , where would the maximums occur?

11. Two coils are coupled. One has an inductance of 2 henries, the second 8 henries, the mutual inductance is $\frac{1}{2}$ henry. What is the coefficient of coupling, k ?

12. When a man receives an electric shock from a 125 volt A.C. line and says, "It was like a million volts," just what peak voltage could he have felt?

13. What is the inductive reactance of a $\frac{1}{10}$ henry choke coil when used with a source of 500 cycles? What happens if the frequency doubles to 1,000 cycles?

14. Make a sketch of the antenna coil you have in the radio you examined. Where do the connections from this coil go?

15. A commercial coil on a one inch tube, has 105 turns which occupy $2\frac{1}{2}$ inches. What is the inductance in microhenries as given in the chart? (Microhenries is abbreviated uhs.)

16. If you can obtain a burned-out power transformer, take the laminations out and study the method of assembly.

17. A transformer for 110 volt operation has a 275 turn primary. Assuming perfect operation, how many turns will be needed for the secondary to produce 5 volts? How about 6.3 volts, and 700 volts?

18. Explain how a transformer can be used to perform all three of its functions in a single circuit.

SELF-TESTING QUESTIONS

7. Remember that the magnetic lines of force set up by any small section of the wire will link all other sections.

10. If you need help, refer to page 75.

11. Simply substitute the values in the formula for the coefficient of coupling.

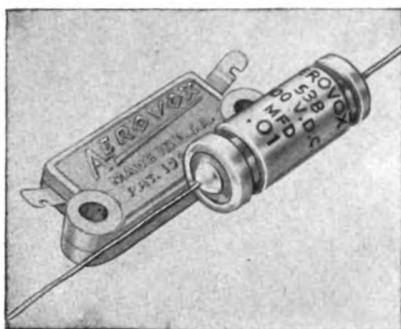
16. If you care to try your hand in re-winding a transformer, a government publication explaining this work can be ordered from the publishers of this course for 25c. This charge is made for the booklet and handling.

18. The three functions are: voltage changing, impedance matching, and segregation of circuits.

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LESSON 6

This is an important lesson because condensers are the most commonly employed parts of radio circuits.



Ultra-small oil-impregnated oil-filled capacitors for use in assemblies where both space and weight are at absolute minimum, are made by Aerovox Corporation. Originally designed as metal-cased alternates for mica capacitors, these oil tubulars are now being used for newly-designed equipment.

Properties of Condensers

ELECTRIC CONDENSERS. When two metal plates are placed close together but separated by an insulator, a condenser is formed. If a condenser is connected to a source of D.C. potential such as a battery, the negative side will become charged with electrons. If the battery connections are removed and the leads to the condenser shorted, a spark will jump across the point of contact, and the two plates will again be in electrical equilibrium; that is, will be neutral. The strength of the charge will depend on a number of factors as we shall see later.

DIELECTRIC MATERIAL. A condenser must have two plates made of conducting material, and a separation of a non-conducting material or vacuum. The material between the plates is called the *dielectric*. Any insulator will serve as the dielectric, but only a limited number of insulators have characteristics that make them especially well suited for this application. Mica, wax-paper, air, and oil are used as the dielectric material in radio condensers. The dielectric constant of air is taken as one. Other substances, used as dielectric materials in condensers, have various values usually greater than one. Mica may have a dielectric constant of 7; this means that if two identical condensers are made, one using air and the second using mica as the dielectric, the capacity or storing ability of the one with mica will be seven times greater.

LOSSES IN CONDENSERS. Every condenser has certain losses which are almost negligible in a high quality unit. For one thing, there is an actual resistance loss in the conducting plates of the condenser. The dielectric, while having very high insulating value, does permit a certain leakage. A practical condenser, therefore, may be assumed to be a perfect condenser with no losses, and having a resistor connected in series to represent the loss in the conducting plates, and a resistor in parallel to represent the leakage. Because of the leakage loss, a charged condenser will soon lose this electrical charge. There are also other losses, but they are not of importance from the practical point of view.

UNITS OF CAPACITY. The degree of ability of a condenser to store electrical charges is known as the *capacity* of the unit. Since the quantity of the electrical charge depends directly upon the voltage of the source, capacity is defined in terms of not only how much charge is stored, but also on how much voltage is applied. The unit of capacity is the *farad*. The farad is the capacity of a condenser that will store one coulomb of electricity at the pressure of one volt.

The farad is much too large a unit for radio applications, the microfarad or mfd., equal to one-millionth of a farad, is commonly used. Condensers of very small capacity also are rated in still smaller units of micro-microfarads or mmfd. which are equal to one-millionth of a microfarad.

CONDENSER CIRCUITS. Condensers, similarly to resistors, may be connected in series and in parallel. When condensers are con-

nected in parallel, the final capacity is greater than that of any condenser used in the combination. The total is equal to the sum of all the individual condensers connected in parallel.

$$C_p = C_1 + C_2 + C_3 + \dots$$

Where C_p is the total capacity of the units in parallel. This formula suggests a means of obtaining larger capacity from a number of smaller units. Each condenser used, however, must be able to withstand the applied voltage of the circuit. Should 15 mfd. be required and only 5 mfd. units be on hand, three of these may be employed connected in parallel with equally satisfactory results as might be obtained from a single 15 mfd. condenser.

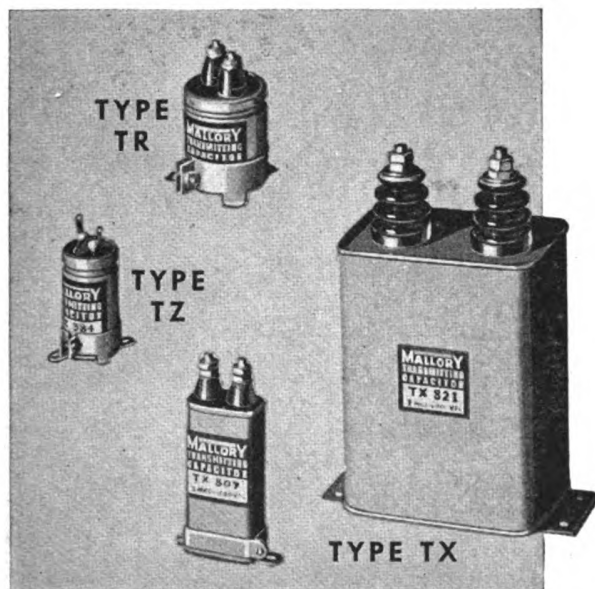


Figure 91. If a condenser is to be used with high voltage circuits, the dielectric must be thick to withstand the high voltage, and the units are quite large. Stand-off insulators are used to prevent arcing to the metal container.

When condensers are connected in series, the final capacity of the combination is always less than that of the smallest condenser used in the combination. It is very rarely that condensers are used in series, except when all are of the same capacity. In such cases the total capacity

$$C_s = \frac{C}{n}$$

where n = number of condensers of capacity C , connected in series.

FACTORS INFLUENCING CAPACITY. There are three factors affecting the capacity of a condenser.

- (1) The type of dielectric used
- (2) The area of the plates in contact with the dielectric
- (3) The actual thickness of the dielectric; or, what is the same thing, the separation between the plates.

It has been found that the capacity of a condenser, using air or other substances for the dielectric, changed for each definite substance used. For example, certain wax-paper employed for the

CONDENSER CIRCUITS

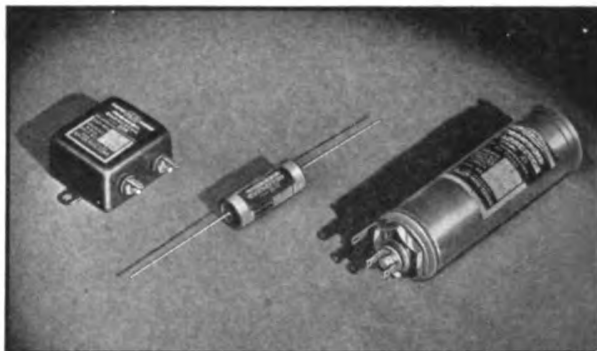
Please observe that the formula for condensers in parallel corresponds to the formula for resistors connected in series.

A certain minimum spacing between plates must be employed to prevent the voltage existing on the condenser from puncturing the insulation.

CONDENSERS USED IN RADIO

Usually the capacity of the condenser is marked on the label of the unit and the maximum permissible voltage, which may exist in the circuit where this condenser is used, is also given.

dielectric made a condenser have twice the capacity than this same condenser had with an air dielectric. Bakelite gave a value $6\frac{1}{2}$ times as large as air; etc. This property of different materials used for the dielectric of condensers is known as the dielectric constant.



Courtesy Solar Mfg. Co.

Figure 92. Here are three types of commonly used radio receiving set condensers; a paper condenser in a metal can, a tubular paper-dielectric condenser, and a metal-can electrolytic condenser.

The actual capacity of different condensers may be calculated from formulas, but the serviceman uses commercial units, supplied with the capacity indicated and, for the serviceman, there will be little need for such calculations. Certain test-analyzers have provisions for indicating the capacity of paper and electrolytic condensers directly.



Courtesy Solar Mfg. Co.

Figure 93. Special condenser testers are available. The unit illustrated gives direct reading of the capacity of the condenser under test.

FIXED CONDENSERS. Condensers commonly used in radio sets are so constructed that their capacity is fixed at one definite value. The exception is the variable condenser used for tuning the radio circuits to receive definite stations. For low capacity, under .02 mfd., mica insulation may be employed. Such condensers are molded in bakelite and are unaffected by moisture. The value of capacity is marked on the case or a color code scheme is used to indicate capacity. Usually three color dots are employed. The

first dot represents the first figure, the second dot represents the second figure, and the third dot tells us how many zeros follow. The number obtained is the capacity of the condenser in micro-microfarads. Use the standard resistor color code scheme. Larger condensers are made with paper dielectric, in tubular form. We urge

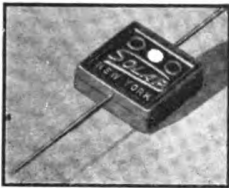
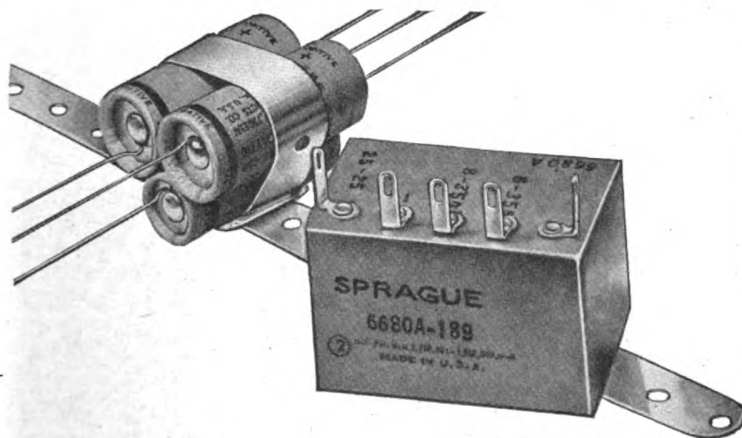


Figure 94. Small size capacitors use mica as the dielectric. These condensers have high voltage break down. The condensers are encased in bakelite and have wire leads.

you to note carefully, (1) the relation of capacity, breakdown voltage or the working voltage, and the physical size, (2) the general appearance of the units, and (3) the general methods used for connecting the units into the circuits.

SIMPLE TESTS. While special condenser testers may be used to detect the faults in condensers, a simple practical test will serve the purpose. Connect the condenser momentarily to a source of D.C. potential between 25 and 100 volts. Quickly disconnect the condenser and connect the terminals together. A spark should be noted at the point of contact if the condenser is in good condition.



Courtesy Sprague Products Co.

Figure 95. Several different condensers may be enclosed in a single container. In making a repair, only the section at fault need be replaced.

MAKING REPLACEMENTS. In replacing fixed condensers, the serviceman need not be too critical. A slight difference of capacity will ordinarily not upset the circuit and this is especially true if the unit is used as a filter. 8 or 12 mfd. units may be used for 10 mfd. However, the rated working voltage is important and must not be exceeded. Condensers rated at 550 volts D.C. may be used on any voltage up to this maximum rated voltage, but not above. A.C. voltage peaks are 1.4 times higher than the measured and indicated RMS voltage. For example, 110 volts A.C. has a peak voltage of 110×1.4 , or 154 volts.

ELECTROLYTIC CONDENSERS. An electrolytic condenser is a fixed condenser of high capacity and compact size suitable for use with voltages not exceeding about 550 volts. These condensers must further be used only with D.C. or pulsating D.C. Because of these characteristics, electrolytic condensers are especially well suited for use in radio filter circuits where these advantages over paper type

The gradual change of capacity is not noticed by observing the operation of the equipment, but changes that occur frequently cause intermittent operation and these faults are difficult to detect.

In a later section, you will learn how to test condensers with simple service instruments.

In all instances, try to use a condenser of higher working voltage than the original. This will eliminate the possibility of another failure in the same part.

ELECTROLYTIC CONDENSERS

Special types of electrolytic condensers have been designed for use on A.C. Condensers are commonly employed with refrigeration motors to form special starting circuits. These motors are A.C. operated.

condensers are fully realized, and the limitations mentioned are of no consequence.

The electrolytic condenser consists of an anode to which the positive connection is made, the cathode used in conjunction with the negative connection, and the electrolyte. Aluminum is usually used as the anode in condensers for radio application. Other metals such as tantalum and magnesium find some use; the chief advantage of tantalum being its ability to withstand acid corrosion. For the cathode, either aluminum or copper is used in connection with the aluminum anode.



Figure 96. Many modern type electrolytic condensers are of the plug-in type. These condensers may be easily tested and replaced.

Many different electrolytes are used and their choice depends greatly upon the voltages to be applied to the condenser. Sometimes mixtures of two or more compounds are used. The density of the electrolyte varies from a liquid, which contains a fairly large percentage of water, to a paste which is commercially called dry.

The dielectric film forms electro-chemically on the surface of the anode. The properties of the electrolytic condenser are due to this film formation. The exact nature of this film is not known, but it is extremely thin making possible high capacity per unit area. The capacitance of a film formed at 300 volts on aluminum is 0.12 mfd. per square inch, about eight hundred times that of a paper condenser for this voltage. The film is formed by applying a potential of the proper value. The capacity is almost inversely proportional to the potential at which the film is formed.

In the actual circuit, when the potential is first applied, the current is only limited by the resistance of the electrolyte and the external resistance present. Naturally, under this condition high currents flow. The film forms quite rapidly, however, and the leakage current drops to a safe value of about 0.2 milliamperes per microfarad. A radio rectifier circuit takes care of this leakage current without difficulty. The rectifier tube does not heat-up instantaneously and, because of this, the voltage at first is of a small value. This voltage partially forms the film which reduces the leakage current when the rectifier tube heats-up to the full value and supplies the maximum voltage.

PRACTICAL CONSIDERATIONS. Small mica and paper condensers are supported in position with their own leads. Usually these leads are long enough to permit direct wiring of the terminals to be connected through the condenser. The electrolytic condensers are larger in physical size and capacity and must be mounted in place. A single cardboard container or metal can may house several separate condensers, each intended for a specific purpose. At times, some of these sections are interconnected in the container and, therefore, require fewer outside connections.

The best way to learn how condensers are mounted and connected is to look at several radio chassis. It is recommended that at this point in your studies, you remove the chassis of other radio sets, besides the model with which you have worked at first, and carefully study the construction of these sets.

Cardboard containers may be mounted with rivets or small bolts. Some round, upright type cardboard electrolytic condensers have studs which permit the condenser to be bolted to the chassis. Most of the older style metal-container type condensers come with a large nut on a threaded section. In mounting, a hole of the proper size is made in the metal chassis base, the threaded section inserted, and the nut tightened from under the chassis.

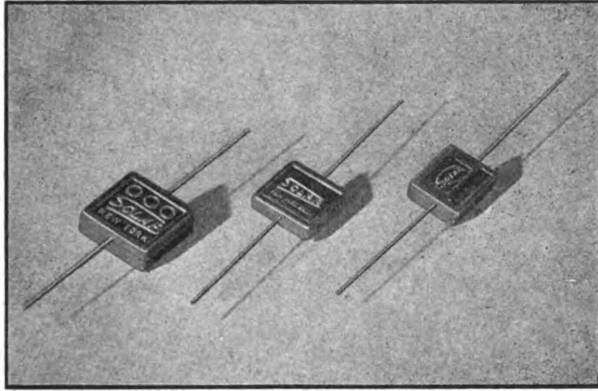


Figure 97. Mica condensers are used in circuits requiring very small fixed capacity, or in circuits where the voltage is above 600 volts, or in applications where the capacity must remain constant for long periods of time.

Mica condensers may be connected with either lead to one of the terminals. No care need be exercised in selecting one of the leads in preference to the other. In the case of paper-dielectric condensers, usually they may be connected also in either fashion as far as the leads are concerned. However, if one lead of the condenser goes to the radio "ground" or chassis, and if the condenser has one lead marked with the word *ground*, then use this lead for the ground connection.



Figure 98. The color code for multi-section condensers is marked on the container. Dry electrolytic condensers may be mounted in any position.

Courtesy Solar Mfg. Co.

The electrolytic condensers, of course, must be connected correctly as far as polarity. The condensers housed in metal cans usually have the can serve as the negative terminal. The other terminal of such a condenser is connected so that a positive voltage is always present on it in relation to the negative terminal. In some units, the metal can may be insulated from all condenser sections contained. In such instances, you will find several colored, insulated, connecting wires coming from the condenser. If the condenser has but one section, only two leads will be needed. Commonly, the red lead refers to the positive connection, the black lead refers to the negative connection. If there are more sections, the color code of the leads is usually printed on the label of the can.

Condenser catalogs, showing the different type units and giving the technical description, are available from the larger condenser manufacturers. You can find these firms' advertisements in radio magazines, and their addresses may be obtained in this manner.

CONDENSERS FOR TUNING

VARIABLE CONDENSERS. Condensers which permit changing of the capacity by means of a manual adjustment are of the variable type. Of such types, the condensers used for tuning will be considered first. You have already examined one of these units in the radio you studied. These tuning condensers may have but a single section. However, most modern radio receivers use tuning condensers which have two or three gangs, or sections. A few sets made around 1928, had five-gang condensers.



Figure 99. Tubular paper dielectric condensers are most commonly used in radio receivers. Electrolytic condensers are also made in tubular shapes as is the unit illustrated.

The frame of the condenser is connected to all rotary sections of every gang. This means that all rotary sections are connected together electrically and, if the condenser is mounted on the metal chassis, these rotary sections will automatically become connected to the radio ground. In some radio sets, an extra wire may be used to *ground* the frame of the condenser, but it is not needed if a good job of mounting is done.

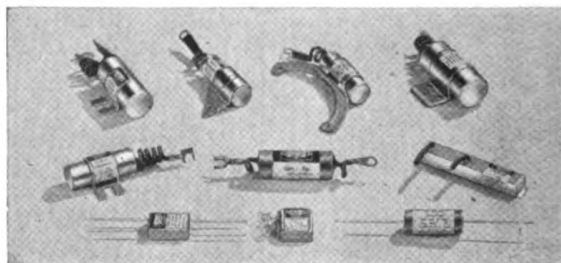


Figure 100. Condensers used for filtering purposes in automobile ignition systems (to eliminate radio interference) are housed in metal containers and are provided with special mounting brackets.

High quality variable condensers use very little insulating material to eliminate dielectric losses and are sturdily constructed so that the corresponding setting will always give the same capacity, and slight jarring of the equipment will not upset the adjustment.

The stationary sections (plates) of each gang are insulated from each other and have separate connections. In fact, each stationary section has two different terminals on each side of the condenser, but electrically these terminals are identical. The reason

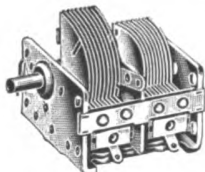


Figure 101. Some variable condensers have one section (gang) supplied with somewhat smaller rotating plates. Such units are called cut-section condensers.

two terminals are included, although they are electrically the same, is to permit wiring to either side of the condenser and, thereby, making the leads shorter. Each gang of the variable condenser is used for tuning a different circuit. Since the capacity of each gang

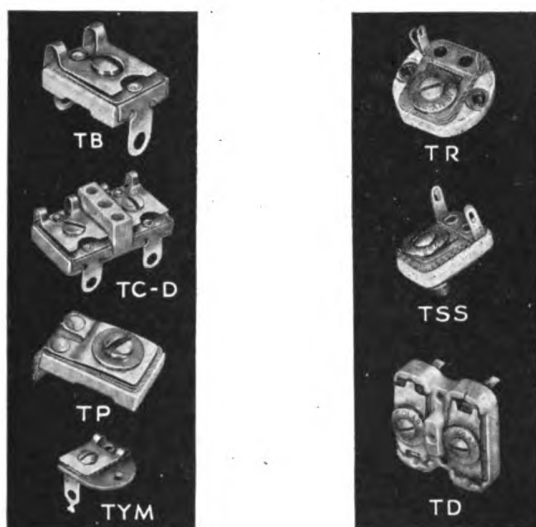
is changed at the same time as the condenser plates are turned (capacity increased or decreased), these circuits are tuned together and kept in step.

Certain circuits require that one gang of the condenser be smaller in capacity at all settings. This is easily accomplished by making one set of rotary plates slightly smaller, so that the capacity of this gang is always smaller. This special type variable condenser is known as cut-plate type, or cut-section type.

In many circuits condensers are needed which must be adjusted on occasion, but once set need not be altered for long periods of time. Such small, adjustable condensers are known as trimmers and padders depending on their application. They are available in maximum capacities from 25 to 1,000 mmfd. As a comparison,

MAXIMUM-MINIMUM CAPACITY

When an extremely large capacity trimmer is needed and this trimmer need be adjusted over a limited range, it is possible to connect a small capacity trimmer in parallel with a fixed condenser.



Courtesy Solar Mfg. Co.

Figure 102. Trimmers and padders are available in various shapes and sizes. Some are dual units. All are semi-adjustable condensers.

usual home radio set tuning condensers have a maximum capacity per gang of 360 mmfd. A good quality condenser having a certain maximum capacity, will give a minimum capacity of about 1/10 the value. For example, if the maximum capacity of a tuning condenser is 360 mmfd., the minimum value, rotating the plates all the way out, will be about 35 mmfd. Please remember this; no variable condenser can be adjusted to give zero capacity.

CAPACITANCE REACTANCE. A condenser connected to a source of voltage, becomes charged with this potential, and tries to keep the voltage unchanged. A condenser attempts to prevent voltage increases by slowing down the action, and tries to overcome voltage decrease by supplying the voltage required. This explanation is not rigorous, but will give you the needed understanding about condenser action. In many ways, a condenser limits changes in voltage in a manner similar to an inductance limiting the action of changes in current.

The tendency of a condenser in preventing the alternating voltage of the source to rise to its true value at the instant, limits the

This action is similar in the *voltage-sense* to inductive reactance when considering its action on current.

CAPACITIVE REACTANCE

You should make up a few problems assuming a suitable frequency and capacity and find the capacitive reactance of the condenser at the frequency assumed. Please notice that as the frequency is increased, the capacitive reactance is decreased.

2. Observe that the larger capacity condensers are almost all of the electrolytic type.

6. Can you tell now why the grid and plate wires should be made as short as possible.

11. The frequency, in this case, is equal to 120 cycles.

12. In practice, after the initial charge, the condenser will not pass D.C.

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current in the circuit, and is, therefore, similar to the effect of a large resistor which could have been in the circuit. This opposition which a condenser offers to the flow of current is known as capacitive reactance, symbol X_c , and is also measured in ohms. We have a formula for calculating capacitive reactance.

$$X_c = \frac{1}{6.28 \times f \times C}$$

where f is the frequency in cycles per second, and C is the capacity in farads. Since most circuits use condensers which are measured in microfarads, we can use a more convenient formula, where the value in *microfarads* can be substituted for C .

$$X_c = \frac{159,236}{f \times C}$$

REVIEW QUESTIONS AND PROBLEMS. 1. If sheets of paper are inserted between the plates of an air variable condenser, will the capacity be increased? Explain.

2. What capacity condensers did you find in the radio set you examined?

3. Using only 8 mfd. condensers, how can you connect these units to obtain 20 mfd. capacity?

4. Can a .01 mfd. 600 volt condenser be used to replace a .01 mfd. 400 volt unit? Explain your answer.

5. On what factors does the capacity of a condenser depend?

6. Is there some small capacity between every two separated conductors? Is this fact of any practical importance?

7. How can a 2 mfd. paper condenser be tested when special equipment is not available?

8. What are the advantages of electrolytic condensers?

9. Why must an electrolytic condenser be connected in the proper fashion?

10. What is the minimum number of separate connections which must be made to a three-gang variable condenser which is mounted on the metal chassis? Can more wires terminate at the connections of this unit?

11. What is the capacitive reactance of a 10 mfd. filter condenser used in a radio power supply which has 120 cycle hum?

12. What happens to the value of X_c as f , the frequency, becomes smaller and smaller? Assume C does not change. What would you conclude as to the value of X_c , as f approaches zero, that is for D.C.?

LESSON 7

L, C, and R, Combined Circuits

PRACTICAL INDUCTIVE CIRCUITS. In discussing circuits incorporating an inductance, we have assumed that resistance was not present. In practice, of course, every coil is made of wire which in turn has more or less resistance. Therefore, an inductance has resistance which behaves as if it is connected in series with the inductance. This behavior permits us to assume, in solving problems, that the inductance has no resistance, but that a separate resistor is connected in series and has the resistance value of this coil resistance.

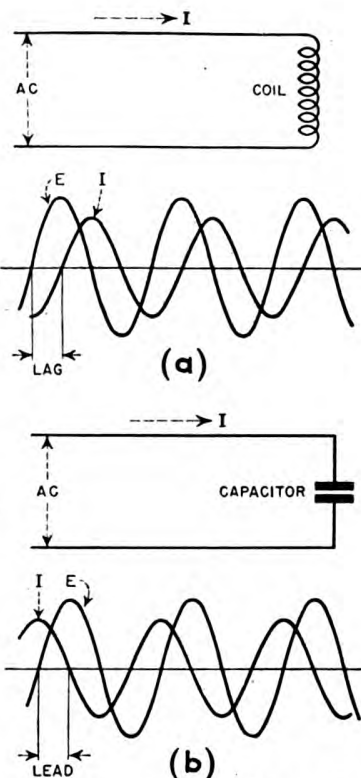
PHASE RELATIONSHIP. In a pure resistive circuit, the current varies with the voltage in accordance with Ohm's Law. The current increases in step with the voltage, and falls to zero when the voltage is zero. In a pure inductive circuit* this is not so. The property of inductance tends to prevent current variations, and although these variations follow the voltage changes, they are somewhat behind in time. There is a period of time after the voltage reaches a maximum value, before the current reaches its maximum value. As the voltage begins to get smaller during a part of the A.C. cycle, the current tries to remain the same, and is replenished in part by the breaking down of the magnetic field. When the voltage returns to zero, the current is still very much present. This phase relationship or time difference between voltage and current is always present in inductive circuits. The current *lags* behind the voltage. In other words, the voltage leads the current. In pure inductive circuits the current lags behind the voltage by 90° . This means that 90 electrical degrees (of time) separate the peak values of voltage and current.

If a circuit has both inductance and resistance, as all real inductive circuits do, the time relationship or phase angle is neither zero as in the case of pure resistance, nor 90° as in the case of pure inductance, but is some value between 0° and 90° . If X_L is much larger in value than the resistance, then the angle is very close to 90° . In a circuit having a large resistance value and very little inductive reactance, the phase angle is close to zero degrees.

IMPEDANCE. Now both the resistance and the inductive reactance of the circuit oppose the passage of electric current. The opposition, however, is not the same since the phase angle causes a difference in the voltage to current relationship. The total equivalent opposition of the two can be found. This total combined opposition is known as impedance and is also measured in ohms. The symbol for impedance is Z .

$$Z = \sqrt{R^2 + X_L^2}$$

The impedance can be found with the aid of this formula if the inductive reactance and the resistance of the circuit are known. In most circuits, the inductive reactance is so much greater than the resistance, that you may assume that $Z = X_L$.



The above illustrations show the relationship between the voltage and current in an inductive circuit and also in a capacitive circuit. It is important to notice that the current and voltage reach their maximum values at a time interval apart. If the circuit is of a pure inductive type, the current will lag 90° behind the voltage. This means that it will take 90 electrical degrees of time for the current to reach the peak point as compared to the instant when the voltage reaches its peak value. Ninety electrical degrees means $\frac{1}{4}$ of 360° which is equivalent to one cycle. Since in a 60 cycle current, each cycle occupies $\frac{1}{60}$ of a second, 90 electrical degrees, in this case, will correspond to $\frac{1}{240}$ of a second.

*This is true to a limited degree in all circuits where inductance is present.

VECTOR REPRESENTATION

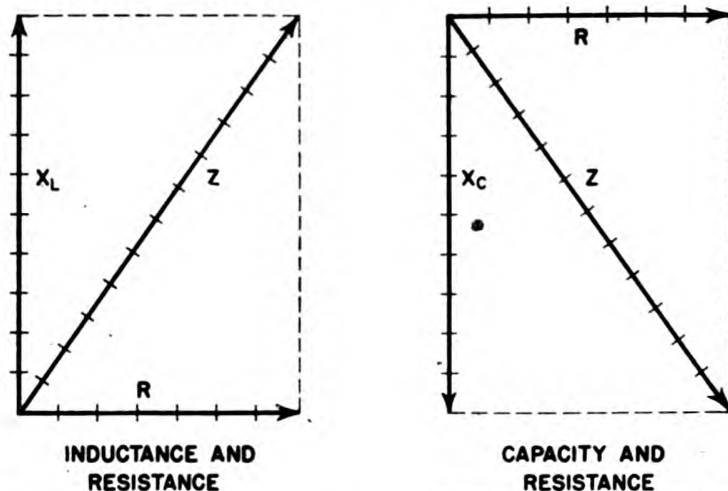
In making geometric representations, the value of resistance is shown as a horizontal line extending to the right. Reactance values are at right angles to the resistance line and are, therefore, vertical. Inductive reactance line is made upwards and capacitive reactance is made in the opposite direction (downwards) since it acts to neutralize inductive reactance.

If the equivalent reactance is considered one side of a triangle, with the resistance line forming another side, the triangle can be completed with a third line joining the extreme points of these lines indicating reactance and resistance. The phase angle (the angle in degrees indicating the phase difference between voltage and current in the circuit) can be measured by the actual angle formed by this connecting *slant* line and the base line which is representative of the resistance. If the reactance is missing, the angle will be zero (there is no angle formed), and this is as expected. In a pure inductive circuit only reactance will exist and there will be no resistance. In this case, the angle will be formed by the vertical reactance line and will indicate 90°, the correct value. For capacitive reactance the angle is negative and this indicates that the voltage lags instead of current.

This is not a formal definition of *Q*. By expressing *Q* in terms of energy stored and used per half cycle, the figure of merit can be applied to cavity resonators and other special (not coil types) tuned circuits.

GEOMETRIC CONSIDERATIONS. It is possible to represent resistance value by a straight line. The actual size of the line will depend on the resistance. You may let one unit of size equal one ohm of resistance or perhaps five ohms. Referring to the illustration, you will see that the line *R* represents the resistance as 7 units long.

In order to represent reactance (either inductive or capacitive), another line may be used. Here again, the unit of size represents a number of ohms of reactance. Since the voltage across the



Drawing courtesy Allied Radio Corp

Figure 103. The value of impedance can be obtained with the aid of vector diagrams.

resistor and the reactance are 90° out of phase, these two lines are illustrated at right angles (90°) in respect to each other.

It is possible to combine resistance and reactance of a series circuit without any formulas, but by using geometric means instead. To do this, the value of resistance and reactance are indicated as straight lines at right angles to each other. (See figure.) Then, using these two lines as two sides of a rectangle, the other sides are sketched in as shown by the dotted lines. Then, the diagonal line is placed and is equal to *Z*, the impedance, of the combination. By measuring the number of units the *Z* line occupies, you can find the actual value of impedance. A similar process is used for inductive or capacitive circuits.

WHAT IS *Q*? Usually reactance is the desired characteristic of a coil while resistance is not. A figure of merit for coils is needed to enable us to judge between various coils. We call this figure of merit for comparative purposes, *Q* and consider it equal to the inductive reactance divided by the R. F. resistance.

$$Q = \frac{\text{Reactance}}{\text{Resistance}} = \frac{X_L}{R} = \frac{6.28 \times f \times L}{R}$$

Since both the reactance and resistance increase with frequency, but not in the same order, the *Q* of coils will vary with the frequency used for the test. In the broadcast band, 540 to 1,750 kilocycles, the *Q* of coils increases for higher frequencies and special methods are used to "even it out" for the entire band. The *Q* determines the gain one obtains from a coil. The voltage step-up is approximately equal to the *Q* of the coil. Broadcast coils have a value of *Q* between 75 and 200.

LOSSES IN COILS. Certain losses are found in all coils and these act in the manner to make the equivalent R. F. resistance appear higher, thereby lowering the Q of the coil. The losses may be due to resistance of the copper wire, dielectric losses in the core material and wire insulation, presence of metal in the coil supports and lugs, losses in the shielding material, and increased resistance due to the tendency of the R. F. current to remain on the surface of the conductors.

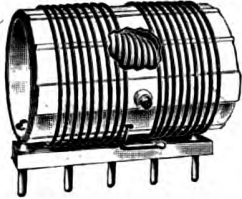


Figure 104. Radio transmitter coils have small losses and may be of the plug-in type to permit easy exchange. Notice that the cut-out shows a small variable coil inside the larger coil form.

Courtesy E. F. Johnson Company

CIRCUITS WITH C AND R. We have already mentioned that all condensers had losses and these could be represented as the losses created by a resistor connected in series with a perfect condenser of the same capacity as the unit we are considering. In many circuits, an actual resistor may be connected in series with a condenser to accomplish the results required by the circuit. Here, as in the case of a L and R circuit, the phase relationships differ and the reactance of the condenser and the resistance of the resistor must be combined in a special way to obtain the total opposition or impedance of the combination. The impedance in this case is,

$$Z = \sqrt{R^2 + X_C^2}$$

In solving a problem, X_C is found first from the formula you already know, then this value and the value for R , are substituted in the above formula, and the answer for the impedance is obtained.

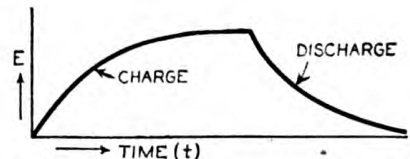
TIME CONSTANT. If a condenser is made to discharge through a resistor, a period of time will pass before the condenser loses a fraction of its charge. The time required for a condenser to lose that part of its charge which will cause the voltage to fall to 37% of its initial value, is called the *time constant*. Expressing time in seconds as t , resistance R in megohms, and C in microfarads, we have a very handy formula,

$$t = R \times C$$

Time constant is very important in the study of automatic volume control circuits which will come up in a later chapter.

CIRCUITS WITH C AND L. You probably recall that an inductance causes the voltage to lead the current (or the current to lag behind the voltage). You also know that, on the contrary, capacity alone causes the voltage to lag the current. The effects are opposite to each other. Now if a circuit has both capacity and inductance, one will partially overcome the effects of the other. The entire circuit will act as either inductive or capacitive reactance depending on whether X_L or X_C is larger for the particular frequency. If the inductive reactance is greater than the capacitive reactance, then some of this X_L will overcome the X_C , and the balance of the inductive reactance will be left.

Notice the similarity of this formula with the one for obtaining the impedance in an inductive circuit.



This curve shows the actual voltage that exists on a condenser which is initially connected to a source of voltage. You recall that a condenser tries to keep the voltage of the circuit at a fixed value. Since the condition, before the connection is completed, represents zero voltage; the voltage across the condenser will increase slowly with time. Theoretically, the total voltage of the source never appears across the condenser. From a practical point of view, however, the full voltage (as close as can be measured with instruments) appears across the condenser after a very short time. Both the charging and discharging curves are similar in character. They are steep at first and then become almost horizontal indicating little additional change in value.

RESONANCE PHENOMENON

The student is reminded once again the inductive reactance and capacitive reactance have neutralizing effects upon each other. It is the nature of electricity to behave in this fashion in conjunction with inductance and capacity. It is this remarkable property that permits radio transmission and reception.

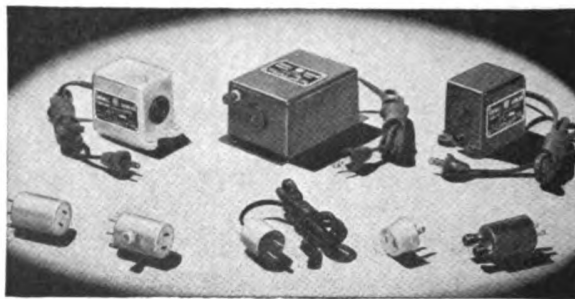
VARIATIONS WITH FREQUENCY. In working several problems, we have already noticed that inductive reactance increases with the frequency, and becomes very large at high frequencies. But capacitive reactance decreases as the frequency is increased, and is almost zero at very high frequencies. It is obvious that given any coil or any value capacity, we can make the reactance any value we please provided we can change the frequency.

RESONANCE. If we have a circuit where a condenser and coil are connected in series, we can select a frequency for which the inductive reactance will be exactly equal to the capacitive reactance. In such instance, the reactance will be entirely eliminated, and only the resistance of the circuit will be present. Let us see what special frequency will cause the reactive components to disappear and produce *resonance*. This condition requires X_L to equal X_C , so we will place the terms defining these reactances equal to each other:

$$6.28 \times f \times L = \frac{1}{6.28 \times f \times C}$$

where L is in henries, and C is in farads. When we solve this equation for f , we obtain:

$$f = \frac{1}{6.28\sqrt{LC}}$$



Courtesy Cornell-Dubilier Elec. Corp.

Figure 105. Condensers and condenser-inductance combinations are used in interference filters to prevent man-made static from reaching radio receivers.

In any circuit where the inductance and capacity are lumped* there is one, and only one frequency, for which the circuit will behave as if only resistance is present and will offer the least impedance. This fact permits the selection (tuning) of a single frequency.

*An inductance or capacity is lumped if the part has only the characteristic of a fixed value of inductance or capacity for all frequencies employed with the component. Most commercial coils and condensers are of this type.

You can see from this important formula that many different values of L and C will produce resonance at a given frequency. Tuning is accomplished in this manner. The coil, L , is fixed, and the condenser, C , is varied to obtain the frequency of the desired station. At resonance, the current in a series circuit is a maximum, and the voltage across either the coil or condenser is also a maximum. At resonance, the voltage across the coil is about equal to Q times the impressed voltage. This explains why a tuning coil and condenser give a voltage gain about equal to the Q of the coil employed.

An interesting experiment can be performed to illustrate the action of resonance. A regular electric light is connected to a 110 volt circuit and, of course, lights up brightly. Now, a large choke coil (inductance) is connected in series with the bulb, and the bulb lights up very dimly. The choke is then replaced with a condenser of large capacity and again the bulb does not light

very brightly. As the final step, we connect the bulb, choke, and condenser in series across the 110 volt line. If we have properly selected the C and L to give resonance at 60 cycles, the bulb will light just as brightly as it did when it was alone in the circuit.

A series resonant circuit will offer very low impedance to frequencies near the resonant frequency. Impedance to frequencies away from resonance will be high. At the resonant frequency, the series circuit consisting of L, C, and R, will act as a pure resistance. At frequencies above resonant frequency, the circuit will behave as if only inductance and resistance are present. Below resonant frequency, the circuit will show effects of capacitive reactance and resistance.

The current in a series L, C, and R, circuit is greatest at resonant frequency and is of the same value in all three components. The voltage, however, need not be the same in the elements used. Since the voltage across any element is the product of the current and the reactance or resistance of that element, it may vary for different frequencies. For example, to find the voltage drop across a condenser, the X_C of this condenser at the frequency used must be calculated. Then the current in the circuit must be figured out and multiplied by the value of reactance obtained. At resonance, the voltage drops across the inductance and capacity are equal in value but opposite in sign.

PARALLEL RESONANCE. When you have a coil and condenser connected in parallel, you must bear in mind that both components have losses which are equivalent to small resistors being connected in series with each item. The calculations then become very difficult. It is common in practice to assume that the condenser has no losses; this is permissible since the losses are very small. The coil Q is calculated by using the formula and substituting the values of R, L, and the frequency employed. After this operation, the coil *series resistor* is also ignored, but instead a fictitious resistor is assumed to be connected in *parallel* with the coil and condenser. This resistor will permit the needed calculation to be performed in a simplified form and is equal to the coil resistance multiplied by Q of the coil, squared.

$$\text{Imaginary parallel resistor} = R \times Q^2$$

For example, considering a parallel circuit where the operating frequency will be 2 megacycles, or 2×10^6 cycles; L is 100 uhy. or 1/10,000 henry; R, the resistance of the coil, is equal to 20 ohms. Calculating Q, we obtain about 63. Now we can assume that the circuit is made up of the coil and condenser, and a new parallel resistor having a value equal to RQ^2 , or $20 \times 63 \times 63 = 7,938$ ohms. Please notice that the higher the Q, the greater will be this equivalent parallel resistor.

In a low loss parallel L-C circuit, it is possible to obtain the resonant frequency using the very same formula employed in series resonance. Please notice these differences. The voltage across the inductance and capacity is equal at all times, but the current may differ a great deal. The impedance of the combination is very high at resonance, approximately equal to the imaginary resistor we have considered. The circulating current between the branches may be very high. At frequencies above resonance, a parallel L-C circuit acts capacitive; at frequencies below resonance the circuit acts inductive; and at resonance, the circuit behaves as pure resistance.

BEHAVIOR AT RESONANCE

Actually, you are performing a similar experiment every time you tune your radio and adjust it to receive a definite station.

The voltages across the reactive elements of a series circuit may be many times greater than the impressed voltage. In working with radio frequency circuits, you must make certain that the condensers employed can withstand the extremely high voltage which may occur at times. For by-pass purposes, mica condensers are recommended.

This method of calculation is well adaptable to practical problems. A parallel resonant circuit, made up of a low loss condenser and coil, at resonance, will have very high equivalent resistance.

If a parallel L-C circuit is to act as an inductance, the impressed frequency should be lower than the natural resonant frequency of the circuit.

QUESTIONS AND ANSWERS

2. You substitute zero for X in the formula.

5. For how many different frequencies is your answer applicable?

6. The answer is: 1,592,000 cycles, or about 1,600 KC.

8. In practical circuits, of course, resistance is always present.

9. You should understand and remember this answer. This is a very important fact and is used in adjusting radio transmitters.

REVIEW QUESTIONS AND PROBLEMS. 1. Explain the phase relationship between voltage and current in an inductive circuit. What is the relationship in a resistive circuit?

2. In a circuit made up of two 20 ohm resistors what is the total impedance of the circuit? Can the regular formula for Z be used?

3. What must be known about a coil in order to calculate its Q ?

4. How long will it take for .5 mfd. condenser to lose 63% of its voltage while discharging through a 500,000 ohm resistor?

5. Is it possible for a circuit having both inductance and capacity to act as a pure resistor? Explain your answer.

6. A coil of 100 microhenries and a condenser of 100 mmfd., are used in a series circuit. What is the resonant frequency of this circuit? Hint: Write 100 uhy. as 10^{-4} , and 100 mmfd. as 10^{-10} .

7. At a frequency higher than resonant frequency, does a series L-C circuit act inductively or capacitively? What about a similar circuit, but of a parallel type?

8. If a parallel L-C circuit has no losses (that is, has no resistance), will the Q of the coil be very high? Will this make the circuit have very high impedance at resonance? Give reasons.

9. In order to make a parallel L-C circuit act inductively, must the exciting frequency be higher or lower than the resonant frequency?

LESSON 8

How Meters Work

ELECTRICAL MEASUREMENTS. The factors associated with electricity are measured, in most practical applications, with the aid of meters. As you probably know, a meter has one or more scales and a movable pointer. For any one condition of measurement, the needle (pointer) stops at a definite place and the corresponding reading of the scale indicates the value being measured. Many electrical measurements are made directly with a meter. For example, voltage is measured with a voltmeter which gives direct reading. Inductance, on the other hand, may be measured directly only with a complex circuit and a specially calibrated meter; simple meters will serve to give indirect measurement and will necessitate the use of a formula for the solution.



Figure 106. Meters, used individually or in radio test equipment, depend on magnetic effects for their operation.

Meters are used to inform the operator that the circuits are functioning correctly at all times; meters help a radio serviceman locate the faults in a piece of equipment; meters help a radio design engineer work out a new circuit with the least guess-work. The radio serviceman, while trouble-shooting, tries to discover the presence of an incorrect electrical quantity in the circuit and such a discovery helps the radioman to locate the actual fault.

While magnetic, heating, or electro-chemical effects may be used to measure electric current, for D.C. and A.C. of lower frequencies, the magnetic effect is employed. For higher A.C. frequencies (such as R.F.), the heat produced is used as the indicating effect. It is important to realize that electric *current* operates all meters. Even when voltage is being measured, it is the current that operates the meter and is the quantity really being measured. But the amount of current present depends on the voltage and, therefore, the scale can be calibrated in terms of voltage.

D.C. METER MOVEMENT. Most of today's direct current meters use D'Arsonval type movement. This movement is sometimes called the permanent-magnet moving-coil type because of the components used. You will notice that in the cut-away view, a large horse-shoe magnet forms the bulk of the unit. Between the pole pieces, a light movable coil is suspended on pivots. You can see one spring in front of this coil, while a second spring, tending to

The meter needle may be of the knife edge type or may be in the shape of an arrow. The knife edge permits finer degree of reading. The thicker arrow pointer is easier to follow and the needle is stronger. The meter scale should always be read from a position directly in front. If a mirror slot is included behind the needle, your eyes should be in a position where you can see the actual pointer but not the image of the pointer in the mirror which will then be blocked with the actual object.

Lately, cathode ray visual equipment is replacing meters for many of these applications.

The fact that current is used to operate all meters is also true in case the meters are of the A.C. type. The more sensitive meters take very little current for their operation.

D'ARSONVAL MOVEMENT

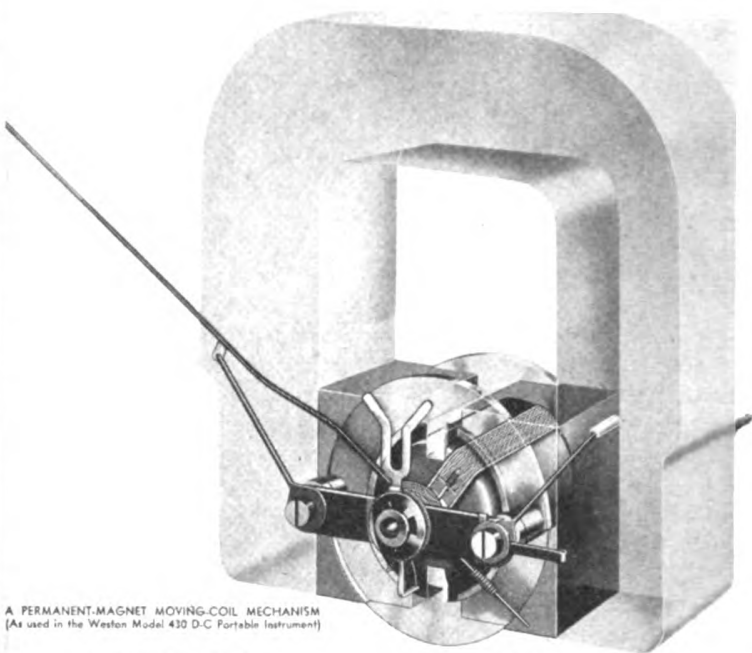
This phantom view of a meter movement should be studied carefully. The understanding of meter construction will help you to use the meters properly and exercise needed care.

A set screw on the face of the meter may be used to preset the needle to the zero position. This adjustment is made while the meter is not connected; the adjustment may be required from time to time since the springs may give from constant tension.

The meter movement is pivoted on fine jewels as used in fine watches.

Many very sensitive meters require considerably less current for maximum deflection. However, one milliamperere movement meter is very popular in radio service work.

turn the coil in the opposite direction, is behind the coil. Since the two springs try to turn the movable coil in opposite directions, it remains in the normal position indicated. The springs are used also to conduct current to the coil from the fixed terminals.



A PERMANENT-MAGNET MOVING-COIL MECHANISM
(As used in the Weston Model 430 D-C Portable Instrument)

Courtesy Weston Electrical Instrument Corp.

Figure 107. This illustration will permit you to understand the operation of a D'Arsonval type movement. The entire movement, in practical units, is housed in a case, and the meter scale is directly under the pointer.

When current flows in the movable coil, an electromagnetic field is produced. The field of this magnet bucks the field of the fixed magnet, and the coil tries to rotate to the right and line up better with the lines of force of the permanent magnet. The intensity of this effort is proportional to the current and also depends on the design of the meter. Since the same amount of current will always rotate the coil and the attached needle to a definite position, a calibrated scale can be mounted on the meter movement, behind the pointer, to indicate the actual value of the current present.

INCREASING CURRENT SCALES. Since a great many turns of very fine wire are used for the coil of a meter, and the *movement* is finely balanced requiring very little power for rotation, small amounts of current will rotate the coil and pointer to the maximum position. A great many meters used in radio work have a 1 ma. movement. This means that only one milliamperere will be needed to swing the pointer to the extreme right hand position. Greater current than this will tend to swing the needle beyond this point and may bend the pointer. Excessive currents may also burn out the coil.

Currents which must be measured in radio work are usually greater than the small current required for maximum movement of the meter pointer. Some method is needed to make a sensitive meter read any current that may be encountered in radio and

electrical work. We have already found out that meters are rated in terms of the current needed to cause maximum deflection of the pointer. Meters are also rated in terms of the D.C. resistance of the moving coil. This resistance varies in different units, but for our discussion we will assume that our meter is of 100 ohms internal resistance, and is of one milliamperes sensitivity. Let us require a meter than must measure currents up to 10 ma. This means that the maximum point on the scale of this meter must be 10 ma., and the normal position, of course, will indicate zero. What circuit must be used to accomplish this?

If we connect a resistor in parallel with the meter, a part of the current being measured will pass through the resistor and a part will pass through the meter. If we wish to measure exactly 10 ma., and if we want the meter to have the needle at the extreme right hand position for this current, we must work out a circuit of this type selecting the value of the resistor to leave only one milliamperes for the meter. You probably recall that 1 ma. is the current required to deflect the needle to the extreme right hand position. Now if *one* milliamperes is to pass through the meter, when we are measuring *ten* milliamperes, then 9 ma. must pass through the parallel (shunt) resistor. The resistor, in this case, must pass nine times the current of the meter. The resistor, therefore, must be smaller in resistance than the meter; it must offer less opposition. In fact, the resistor must be $1/9$ the size of the meter resistance to pass nine times the current.

Recalling that the meter resistance, in our example, is 100 ohms, $1/9$ of this amount gives about 11.1 ohms. This is the value of the shunt resistor needed. This resistor must be accurate (one or two percent in practice) to give a fair degree of accuracy when used with the meter. For any other current scale requirements, the same process is applied. You will notice that if the scale is to be multiplied by a factor n (n may be any number, in our example n was equal to 10), the shunt has a value equal to the meter resistance divided by a number equal to n less one, ($10 - 1 = 9$ in our example).

The scale of a meter may be marked off in divisions, with 10 marking the last point at the right hand side. Marks within each division help you to estimate the exact reading as indicated by the needle. If you are using a scale where the maximum reading is 500 milliamperes, then you must understand that this mark 10 corresponds to 500 ma. In the same fashion, the point 4 corresponds to 200 ma., and a point $2\frac{1}{2}$ corresponds to 125 ma. In these cases, each division is equal to 50 ma., since 10 divisions equal 500 ma. For another maximum current consideration, a different shunt resistor is used and each division may represent a different amount.

MAKING A D.C. VOLTMETER. The meter we have used in our examples was said to be of the one milliamperes movement type and of 100 ohms internal resistance. What voltage will be needed to swing the needle to its maximum position? This is the voltage which will cause one milliamperes (.001 ampere) to flow through the meter resistance of 100 ohms. Using Ohm's Law, we multiply I by R , and obtain $1/10$ of a volt. We see from this that the same meter (it is a current meter called a milliammeter) can be used to measure voltages up to $1/10$ of a volt. A fifth ($1/5$) of a volt will cause the current to be only $1/2$ ma., and the needle

EXTENDING METER RANGES

Meter scales are usually multiplied in units of ten since this simplifies the readings.

When two resistors are connected in parallel, the smaller resistance passes more current.

The shunt resistor should be within 1%, or better, of the required value. The calculation of the resistor size should be carried out to better than 1%. Notice that in our example, we carried out the calculation to within one decimal place, so that the error, at most, could be .05 of an ohm, or about 0.45% (a little under $1/2$ of 1%) of the total shunt resistor value of 11.1 ohms.

The reading of meter scales is similar to reading the scales on a slide rule. Perhaps you had experience in using a slide rule.

MAKING A VOLTMETER

Remember that this meter is still measuring current, but the amount of current depends on the voltage of the source.

A meter is most sensitive and can be read most accurately when the values being measured deflect the needle to about the center of the scale. Poor accuracy is obtained when the reading is taken at either extreme of the scale.

Read this paragraph again. Be sure you understand it. Write the meaning of this paragraph in your own words.

You may think of the meter and the series resistor acting as two resistors in series. There is a voltage drop in each resistor. The design of the voltmeter requires the choice of the series dropping resistor of a value that will cause the voltage drop in this resistor and the meter to be in proper proportion to give needed results.

Later lessons will explain the use of voltmeters for electronic equipment measurements and service work.

will stop in the half-way position.* Yes, we can use a milliammeter for measuring voltage without any other parts, but only voltage up to $1/10$ of a volt in this case. Most voltages encountered in radio work are from one volt to several thousand volts. We must work out some voltage multiplier.



Figure 108. To increase the reading of meters, series and shunt resistors are needed. These resistors are of the precision type, usually 1% accuracy.

We will first consider how to make our meter read up to 10 volts at maximum deflection. If the meter can be made to do this, it will be adaptable to read other values of voltage less than 10 volts. Let us connect a resistor in series with the meter. Please notice that we now connect the resistor in series and not in shunt as before. How large must this resistor be, so that when we are measuring a total of ten volts, the meter pointer will move only to its extreme right hand position, but not beyond? For this condition, the meter requires $1/10$ (or 0.1) of a volt, as we have already found out, and since we have a total of 10 volts, $10 - 0.1$ or 9.9 volts of this must be lost in the resistor. But the current passing through the circuit must be 1 ma. (.001 amperes) when the needle shows maximum deflection, and we can apply Ohm's Law once again. To get resistance, we divide voltage by current. Dividing 9.9 volts by .001 amperes, we obtain 9,900 ohms. Since a 10,000 ohm resistor will represent an error of only one percent, it may be used in a practical circuit. The marked resistor value, however, must be accurate to within 2% to 5%.



Figure 109. Even a voltmeter is a current measuring device. Since the current is proportional to the voltage, the scale can be calibrated in volts.

Courtesy Triplett Electrical Inst. Co.

For any other value of maximum voltage scale, the same procedure of calculation is employed. For example, for 100 volts a resistor of 99,900 (or 100,000) ohms is needed. The switching in of the different resistors may be accomplished with a rotary switch and the scale required may be easily selected.

HIGH RESISTANCE OHMMETER. A milliammeter may be used to measure the value of resistance. Let us see how the milliammeter, we have used for the previous examples, can be made to measure resistance. In your notebook, make a drawing indicating the

*The majority of D.C. instruments have linear scales; equal scale distance for equal electrical units.

meter, a $4\frac{1}{2}$ volt battery, and a 4,400 ohm resistor connected in series. The total resistance of this circuit will be 4,500 ohms, obtained by adding the resistance mentioned to the 100 ohm resistance of the meter. Using a $4\frac{1}{2}$ volt battery with this total resistance, makes the current in the circuit equal to .001 ampere, or 1 ma. With this current passing through the meter, the needle will indicate the extreme right hand position.

Draw the circuit once again, but this time leave a break in the connecting wires at any one point. Indicate terminals at each end of the wire at this break. The two test wires or test leads will be connected to these two terminals. If the terminals are shorted, i.e. connected with a short piece of wire of almost no resistance, the needle will swing to the right. Since the wire has about zero resistance, we mark this point at the extreme right hand of the ohmmeter scale, O . Now let us leave the terminals open, i.e. apart. We are actually measuring under these conditions, the resistance of the air between the terminals. This resistance is very high, running in millions of ohms, and for practical purposes may be considered infinite or the greatest possible value. The symbol ∞ (eight sideways) represents infinity, and since the needle in this case will be all the way to the left, the normal position, we will mark this point, infinity. If we measure a resistor of exactly 4,500 ohms, the total resistance of the circuit under these conditions will be obtained by adding this resistance to the actual resistance of the circuit. Since the result will be 9,000 ohms, twice the circuit resistance, the current will be one-half the maximum value, and the mid-point of the scale will be marked, 4,500. Other points will be obtained in the same fashion.



Figure 110. A meter may have several scales and, when used with a selector switch and the required network of resistors, will indicate various values of current, voltage, and resistance.

Courtesy Triplett Electrical Inst. Co.

An ohmmeter scale is more spread out at the right for low values and is very congested for extremely high values. The ohmmeter we described can be read for values up to about 500,000 ohms, after that the total space of the scale remaining before the infinity mark is reached is so small that no accurate reading is possible. Some ohmmeters, of course, are made to read up to several megohms.

METER ACCURACY. All meters lack perfection of accuracy. In practical work very rough reading is usually sufficient and 5% accuracy is very satisfactory. The errors are due to several causes. The meter cannot be calibrated perfectly. The scales are printed from a drawing which is based on a typical meter of the type considered. However, not all bearings, springs, magnets, and coils are exactly alike and slight variations in responding to the same current always result. The same current, therefore, may give slightly different readings in several similar meters. Errors are also due to the associated resistors and to the width of the pointer.

HOW TO READ METER SCALES. The illustration shows a typical meter panel which incorporates scales for reading various values of voltage, current in milliamperes, and resistance in ohms. This panel agrees with our discussion so far. The rotary switch used

OHMMETER CONNECTIONS

Actually the 100 ohm meter resistance is only 2.2% of the required series resistor. Since this resistor may be accurate only to within 5% in commercial units, a 4,500 ohm resistor will serve. In commercial ohmmeters, this series resistor is made variable to permit adjustment to compensate for age changes of the series battery.

Most students make the error of thinking that when the terminals are apart, the resistance being measured is zero. This is wrong, of course. There is very high resistance between separated terminals, millions of ohms.

To read very high resistance values with some degree of accuracy, the meter movement must be very sensitive or else a very high voltage, series battery and series resistor must be used. For example, a meter of the type we used in our description can be made to read 450,000 ohms in the center (and much higher values at the left side of the scale) if the series resistor is made equal to 450,000 ohms, and a 450 volt supply is used.

READING METER SCALES

It is most urgent that you become expert in reading meter scales correctly. If you have a friend who had more experience in radio work, ask him to test your knowledge in reading meter indications. Excellent review problems are given on page 89.

While the principle of meter scale reading is the same for all units, the actual scales may vary.

Always use a scale that gives the reading near its center.

When the same meter is used for D.C. and A.C. reading, the rectifier unit is switched-in for A.C. use. A new scale must be included for A.C. reading since the meter with the rectifier no longer gives linear scale reading as in the case of D.C.

for the selection of the scale to be employed is usually marked with the multiplication factor and an indication as to whether it is related to voltage, current, or resistance. Let us assume that we are measuring voltage and the multiplication factor is such that the maximum deflection will equal 50 volts. Look at the extreme right row of numbers of the scales on the meter and find a number which goes into 50, once, or ten times, or a hundred times. This number, in this case, is 5. Five goes into fifty, ten times. Read the values indicated by the pointer by making reference to this middle lower scale (the one that has numbers: 0, 1, 2, 3, 4, and 5). Multiply what you read by ten, because of the fact that the full scale deflection in this case is 50 and not 5. Make up a few problems yourself by naming a scale and making a mark for the pointer.

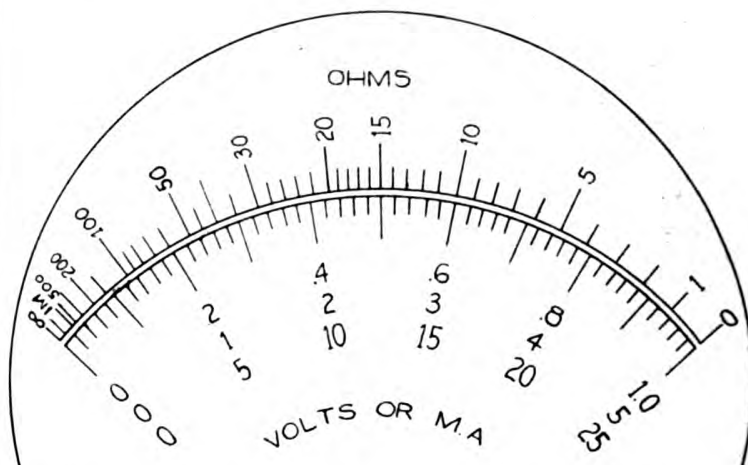


Figure 111. Very often the scale of a volt-ohm-milliammeter test unit will be similar to the scale illustrated. As a future radio serviceman, you must be able to read such scales.

As another example, let us measure resistance and use a position of the switch which calls for multiplying the results read on the scale by a factor of 100. If the pointer stops at 15, you are really reading 15×100 , or 1,500 ohms. What if the pointer stops at the short line after the mark 30, on the upper ohm scale? You see that the mark lies between 30 and 50. The long line between 30 and 50, indicates 40. The short line, where our pointer stopped, lies between 30 and this longer line which indicates 40. It is evident that the pointer must be at a value corresponding to 35. But we are using a scale which requires multiplication by 100, and so our answer is 3,500 ohms.

CONVERSION TO A.C. The meters we have discussed so far can be used with D.C. only. It is possible to use a regular D.C. meter for measuring alternating current or voltage with the aid of a rectifier unit. The rectifier changes A.C. to D.C. and the value of A.C. voltage or current is measured on special scales. Usually these scales are calibrated for a given A.C. frequency, and considerable variation in frequency will cause additional errors. The rectifier elements are made of copper oxide and the current is permitted to pass only in one direction.

A sensitive D.C. meter may be used with a thermocouple to measure alternating currents up to ultra-high R.F. The current to be measured heats a small wire which is placed near a junction of two different metals. When a point of contact of two different metals is heated, a slight voltage is produced. This voltage is D.C. and is impressed on the sensitive D.C. meter.

METERS FOR A.C. MEASUREMENTS

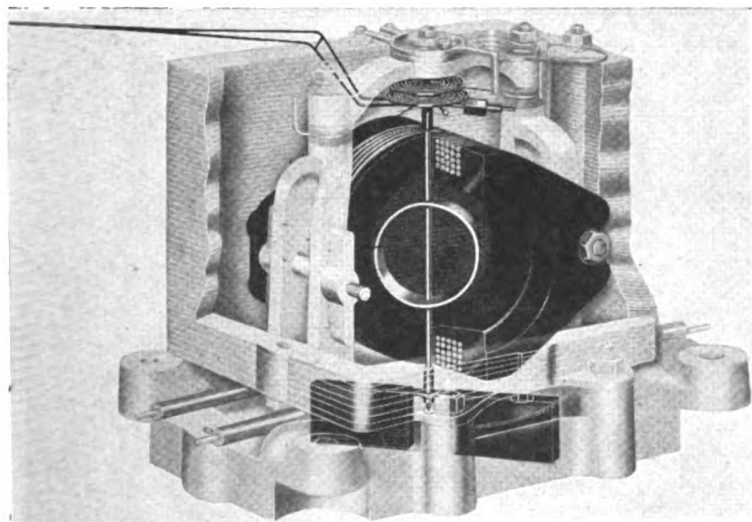
Since different thermocouples convert electric current to heat and heat back to D.C. current in different degrees of efficiency, such an A.C. meter must have its scale calibrated for the particular thermocouple employed.



Figure 112. A.C. meters have the same outward appearance as similar D.C. instruments. However, the movement must be different, or the A.C. must be converted to direct current.

DYNAMOMETER METER. A meter can be constructed to operate directly from A.C. If a D'Arsonval movement meter is connected to alternating current, the needle will try to follow the variations in the current and will appear to be vibrating. No true reading will be possible. Notice the different construction of the electro-dynamometer mechanism which can be used to measure A.C. directly. The large stationary coils are connected to the source of A.C., and a part of this current is conducted through the small

In practice, if a D.C. meter is connected to A.C. in error, the needle may either vibrate or jump to an extreme position.



AN ELECTRODYNAMOMETER MECHANISM
(As used in the Weston Model 432 D.C. and Single Phase A.C. Wattmeter)

Courtesy Weston Electrical Inst. Corp.

Figure 113. Here is an inside view of an electro-dynamometer movement. Notice the large fixed coils and the small rotating coil attached to the pointer.

movable coil. The small coil is mechanically connected to the pointer. Since the current in both the stationary and movable coils reverses at the same time, the torque (movement, rotation) is in the same direction and is proportional to the square of the current.

The moving and stationary coils buck (push) each other in the same relative direction even when the current reverses. There are instants (two in every cycle) when the current is zero and no magnetic field exists, but these instants are short in duration. During such instances, the needle does try to return to the initial zero position, but before it can get started, the magnetic field starts building up once again.

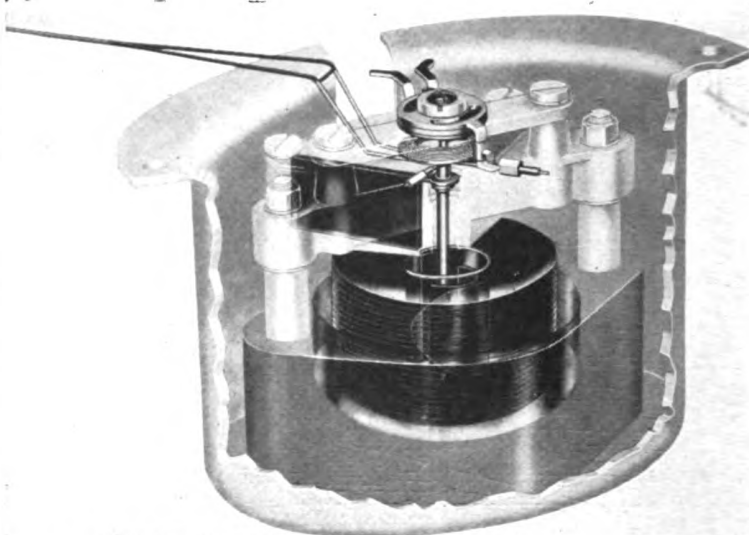
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MOVING IRON-VANE METER

Regardless of the type of movement in the meter, the scales are read in the manner already explained under D.C. type meters. It is more difficult to increase the scale reading of A.C. instruments since the meter does not behave as a pure resistor, but as a complex impedance.

Such meters may be used also for D.C., but they are not as sensitive as the D'Arsonval movement types. Dynamometer movements may be used in ammeters, voltmeters, or wattmeters.

MOVING IRON-VANE METER. This type of meter has a fixed coil which is connected to the circuit having the current to be measured. Usually there is a fixed iron plate and a moving iron-vane. In the normal position, these iron plates are close to each other. The moving iron-vane is connected to the pointer. When current passes through the coil, it creates an electromagnet which in turn magnetizes the iron plates. Since these plates are of the same magnetic polarity at all times, although the magnetic fields of both reverse with changes in the direction of the current, the iron plates repel each other in proportion to the current. This repelling action makes the moving-vane rotate against the tension of the spring. The amount of rotation indicates the quantity of current being measured.



A MOVING IRON-VANE MECHANISM.
(As used in the Weston Model 433 A.C. Portable Instrument)

Courtesy Weston Electrical Inst. Corp.

Figure 114. The moving iron vane meter can be used for A.C. measurements. This movement is not as sensitive as the D'Arsonval movement and, therefore, is not recommended for D.C.

1. How is such a meter made to read zero in the center, and values to the right and left?

2. Answer: 2.08 ohms.

3. Exact size: 499,950 ohms.

REVIEW QUESTIONS AND PROBLEMS. 1. With a rough drawing, explain how a D'Arsonval type movement works.

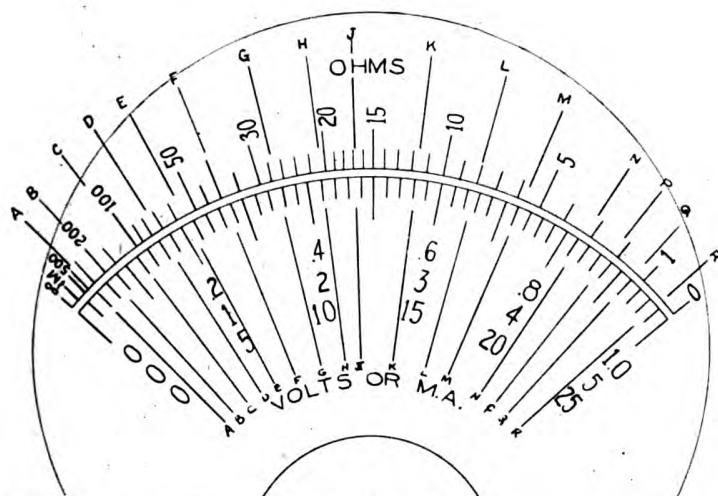
2. What shunt resistance is needed to make a 0 to 1 ma., 50 ohm meter, read 25 ma. at maximum deflection?

3. What series resistance will be required to make the meter of Question 2, indicate 500 volts at full scale deflection? What practical value resistor will be used? How accurate is this resistor in practice?

4. The sensitivity of a voltmeter is measured in "ohms per volt" and is obtained by dividing the voltage needed for maximum scale deflection by the total series resistance of the circuit. What is the ohms/volt sensitivity of the voltmeter in Question 3?

5. Name two methods used to convert D.C. meters to A.C. use.

6. Copy the chart shown, in your notebook. By following the lines marked by different letters, A, B, C, etc., fill in the readings corresponding to different scales. Notice the few sample answers as given.



DEFLECTION	RANGE SWITCH SET TO							
	10 V	100 V	500 V	1 MA	5 MA	25 MA	Ohms x 1	Ohms x 100
A	4							
B							200	
C	DO NOT WRITE IN THIS CHART						3	
D								
E								
F								
G								
H								
J								
K								
L								
M								
N								
P								
Q								
R								

Figure 115. You are to assume that the pointer of the instrument stops at the lines indicated by the different letters, and obtain correct reading with the range switch set at the maximum deflection values indicated in the table.

PRACTICE QUESTIONS

4. This division may be made for any one voltage scale, or for the original meter.

6. This assignment should be carefully worked out. An answer book should be purchased from the publishers of this course. This answer book will permit you to check the correctness of your work. All questions are answered in this booklet which is priced at 25c, post-paid. Do not look up the answers, however, until you worked out the problems yourself.

LESSON 9

Vacuum Tubes

The operation of all electronic equipment is dependent on vacuum tubes. The same types of tubes are employed in radio receivers, small transmitters, and electronic circuits. While the majority of examples presented suggest radio circuits, the same or similar arrangements are used to produce the function of electronic equipment.

This paragraph has much "meat" in it. Study it carefully.

If the filament is used to emit electrons, it is also called the cathode. In indirectly heated tubes, the cathode is a separate element from the filament.

Diode vacuum tubes are used for many special electronic applications. Such tubes are especially useful for producing *square* shaped waves.

ELECTRON EMISSION. You already know that vacuum tubes are used in almost all radio units. The basis of vacuum tube operation, be they rectifiers or multi-purpose tubes, in glass or metal envelopes, is electron emission. Electrons are emitted from an electrically heated filament. This means that an ordinary electric bulb also emits electrons. In electric bulbs, the electrons form a cloud around the heated filament and, as more electrons are emitted, others return to the filament. Electric bulbs and vacuum tubes must have the air removed from the container in order to obtain the needed action and prevent the filament from burning up.

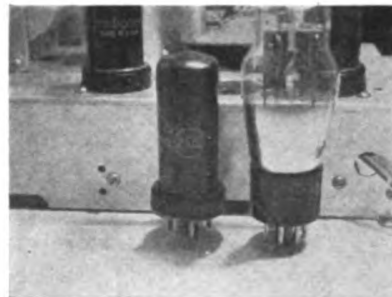


Figure 116. The majority of metal tubes have glass envelope equivalents. All tubes depend on electron emission for their operation.

DIRECTLY HEATED TUBES. Vacuum tubes which have the actual filament emitting the electrons are known as directly heated types. Most battery set tubes, rectifiers, and power tubes are of this type.

INDIRECTLY HEATED CATHODE TUBES. In many tube types, the electrons are emitted from a metal sleeve. This sleeve is placed over the filament, but is insulated from it. The filament then serves only as a source of heat and does not actually emit the electrons used for operation. Most A.C. operated radio tubes used in "sensitive" circuits are of the cathode type. The element emitting the electrons is always called the cathode. Some substances are far better emitters than others. Coating a poor emitter with an oxide of certain metals may raise the emission a thousand times. The emission also increases with the temperature.

DIODES. In 1883, Thomas Edison discovered that when an additional electrode was placed inside an incandescent lamp and this electrode connected to a positive potential with respect to the filament, a current passed through the tube. This is actually a simple vacuum tube of the *diode* type. It contains but two elements, the cathode to emit and the plate (anode) to receive the electrons. Under the influence of a positive potential applied to the plate, electrons will flow from the cathode to the positively charged plate. An increase in the plate potential will increase the plate current. The complete action is easy to analyze.

From a heated cathode many electrons venture out, forming a cloud around it. If a negative potential is applied to the plate, the electrons will be repelled back into the cathode and no current will pass between these two elements. If, however, the plate becomes positive with respect to the cathode, the electrons around the cathode will be attracted to the plate, since unlike charges attract, and current will pass.

SPACE CHARGE. Of the electrons leaving the cathode, not all, of course, reach the plate. Many return to the cathode while others remain for short periods of time between the cathode and the plate forming a *space charge*. The space charge, being made up of electrons, is negative.

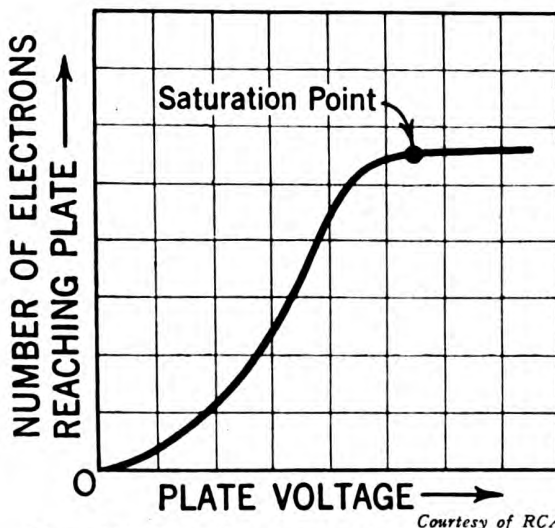


Figure 117. When the voltage on the plate is increased to a value which will force all available electrons to reach the plate, a further voltage rise will not increase the current made up of these electrons.

SATURATION. As the plate of a diode tube is made more positive, a greater number of electrons will be attracted across the space in the tube. Finally, the plate can be so positive that *all* electrons emitted by the cathode will be going to the plate. If the plate is made even more positive beyond this point (this can be done by connecting more batteries to the plate), all the available electrons will continue to be received by the plate. There will not be any increase since there are no more electrons emitted. Now, you know that electric current is made up of electrons, and so a maximum current will be reached. Raising the plate potential (voltage) will no longer increase the current after this saturation point. Up to the saturation point, of course, an increase in plate voltage increases the plate current in the diode. Vacuum tubes are not operated near the saturation point and the plate voltage is kept at a value to prevent saturation current.

Large values of plate current can be obtained by closely placing the cathode and plate in a diode tube. In some rectifier tubes, mercury vapor is introduced to increase the plate current. In such mercury vapor tubes, the voltage lost in the tube itself is very small.

TRIODES. Tubes having a third electrode for control purposes are known as triodes. This control electrode is usually called the

If the plate potential is only slightly negative, a very limited number of electrons (constituting a minute current) may still pass through the tube, from the cathode to the plate.

Please note that under the condition of saturation, a further rise in plate voltage will not increase the plate current. However, an increase in filament voltage which may make the filament (and cathode) operate at a higher temperature, will result in greater emission of electrons and will permit an increase in current. For most circuits, the filament voltage remains fixed at a value needed for the best operation of the particular vacuum tube.

Most vacuum tube circuits are so adjusted that the operation (the average plate current condition) corresponds to the mid-point of the curve shown in Figure 117. Sometimes, certain circuits require operation near the zero-current point.

TETRODES AND PENTODES

Be sure you understand the controlling action of the grid. Try to explain in your own words how the grid reduces or increases the number of electrons reaching the plate.

With the additional knowledge you have gained since last looking at the tubes in your *model* radio, examine the tubes once again. Try to see the inside construction. If you have any burned out or *bad* tubes, break* them. Examine the inside construction and the placement of the elements.

The words *tetrodes* and *pentodes* should suggest to you four elements and five elements, respectively.

*To break the glass of a vacuum tube, wrap the tube in a moist rag. Then hit the glass with a flat surface. A heavy book is excellent for this purpose. This will prevent the glass from *flying* when the tube is broken and the air rushes inside.

grid because it is made of fine wire in the form of a mesh. The grid is placed much closer to the cathode than the plate. The purpose of the grid is to control plate current. With a negative voltage on the grid, the grid exerts a force on the electrons in the space between cathode and grid. This force drives the electrons back to the cathode. In this way, the negatively charged grid opposes the flow of electrons to the plate. When the voltage on the grid is made more negative, the grid exerts a stronger repelling force on the electrons and the plate current is decreased. When the grid voltage is made less negative, there is less repelling force exerted by the grid and the plate current increases. When the voltage on the grid is varied in accordance with a signal, the plate current also varies with the signal. Because a small voltage applied to the grid can control a comparatively large amount of plate current, the signal is amplified by the tube.



Figure 118. Although radio receiving tubes have different physical appearances, it is the inside construction that makes the real difference.

The grid, plate, and cathode of a triode form an electrostatic system, each electrode acting as one plate of a small condenser. The capacitances are those existing between grid and plate, plate and cathode, and grid and cathode. The capacitance between grid and plate is of greatest importance and, in high gain radio-frequency circuits, this capacitance may produce undesired coupling between the input and output circuits.

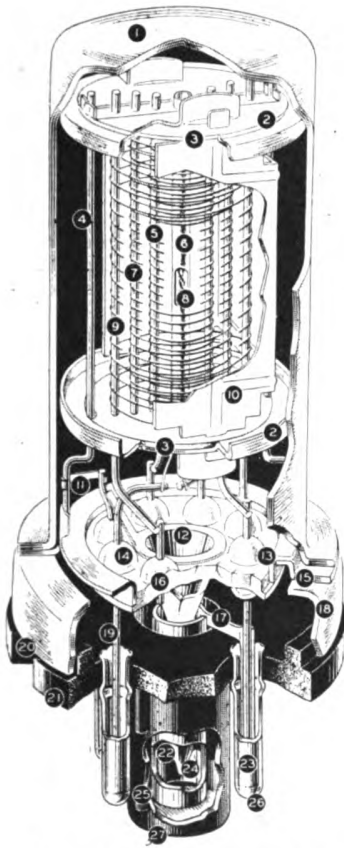
TETRODES. The detrimental effect of the grid-plate capacitance is reduced greatly by the introduction of a fourth electrode, called the *screen grid*, placed between the grid and the plate. This screen, in ordinary application, is connected to a positive potential somewhat lower than the plate potential. Since the screen voltage largely determines the electron flow, large variations in the plate voltage will have but little effect on the plate current.

Electrons striking the plate dislodge other electrons from it. This indirect emission of electrons from the plate is called secondary emission in contrast to primary emission from the heated cathode. In the diode or triode this action does not cause any difficulties because of the absence of any positive bodies in the vicinity of the plate. In the screen grid type tetrode, however, the screen is positive and close to the plate and does attract electrons emitted by the secondary emission action. This effect lowers the plate current and limits the permissible plate swing.

PENTODES. This limitation of secondary emission, in turn, may be removed by a further introduction of another electrode, known as the suppressor, between the screen and the plate. The suppressor may be connected directly to the cathode or, as in some tubes for special applications, have an external prong. Since such tubes have five elements,* they are called pentodes.

*The elements are: cathode, control grid, screen grid, suppressor grid, and plate.

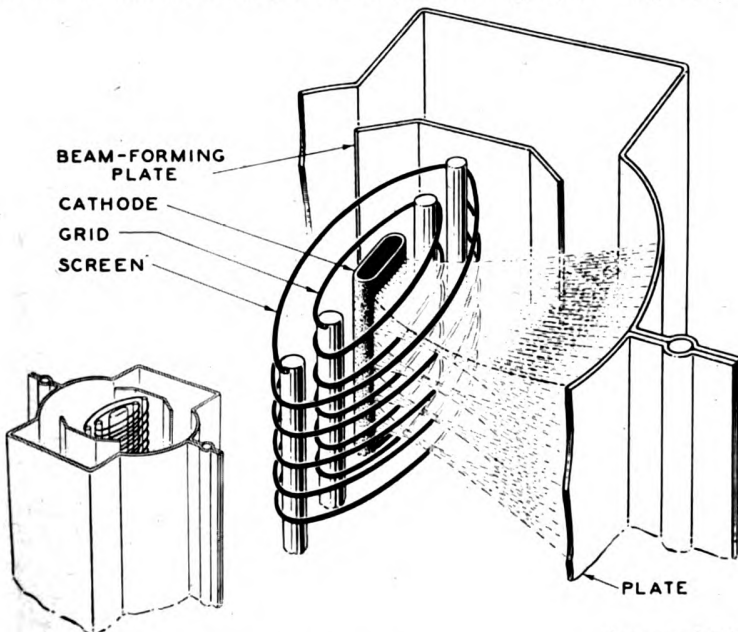
Figure 119. The structure of a metal tube is of interest to the future radio technician. (Courtesy of RCA).



1. Metal envelope
2. Spacer shield
3. Insulating spacer
4. Mount support
5. Control grid
6. Coated cathode
7. Screen grid
8. Heater (filament)
9. Suppressor grid
10. Plate
11. Batalum getter
12. Conical stem
13. Header
14. Glass seal
15. Header insert
16. Stem seal
17. Base shield
18. Header skirt
19. Lead wire
20. Crimped lock
21. Octal base
22. Exhaust tube
23. Base pin
24. Exhaust tip
25. Aligning key
26. Solder
27. Aligning plug

BEAM POWER TUBES. A beam power tube makes use of a different method for suppressing secondary emission. In this tube there are four electrodes, a cathode, a control grid, screen grid, and

Beam power tubes are used primarily for handling considerable power in audio output stages of radio receivers. These tubes also offer certain advantages in radio transmitter circuits. The numbers assigned to beam power tubes incorporate the letter L or V. Did your radio have any beam power tubes?



Courtesy of RCA

Figure 120. The placement of the elements in a beam power tube, and the form of the electron stream. Because of the electron velocity distribution, pentode action is obtained in a beam power tube without a suppressor grid.

EXPERIMENT WITH A TRIODE

Multi-unit tubes give economy of space and a little simplification in the wiring. You will learn that such a tube costs about as much as two single purpose tubes needed to perform the same function.

If you have the needed equipment, you should actually perform this experiment. You will need any standard triode tube, several B batteries (or a power supply with an adjustable voltage output), about six dry cells (or another source of low D.C. voltage), and a D.C. milliammeter.

In practical circuits, of course, batteries are replaced with power supplies which deliver the same types of voltages.

Such wide variation is needed in order to make the complete set of curves as shown in Figure 122. To check one or two curves, only the voltages expected to cause the points on these curves will be required.

plate so spaced that secondary emission from the plate is suppressed without an actual suppressor. Because of the way the electrodes are spaced, electrons traveling to the plate slow down when the plate voltage is low, almost to zero velocity in a certain region between the screen and plate. In this region, the electrons form a stationary cloud, a space charge, which repels secondary electrons emitted from the plate and causes them to return to the plate. In this manner, secondary emission is suppressed. Another feature of the beam power tube is the low current drawn by the screen. Beam power tubes act as pentodes, but have only four elements.

MULTI-UNIT TUBES. Some commercial vacuum tubes combine several tubes in one envelope. For example, a tube may combine two triode sections, having two sets of cathodes, control grids, and plates, but only a single filament. Or another tube may combine a pentode audio output tube and an indirectly heated rectifier.

Certain tubes contain additional elements to serve special purposes. Usually the pentagrid-converter tubes, used in superhet circuits which you will study later, are of this type.

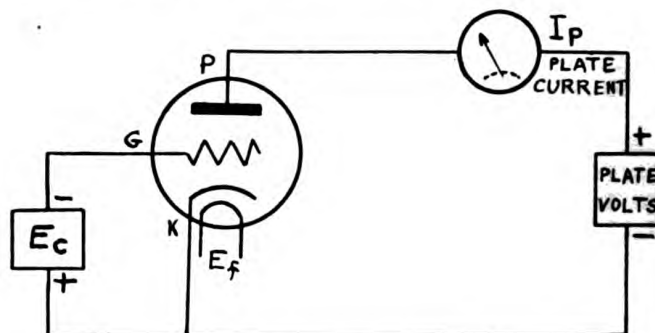


Figure 121. The circuit for the experiment to determine the characteristics of a triode vacuum tube.

PLATE CURRENT OF A TRIODE. You will now learn about a very practical experiment. If the equipment is available, you may follow these instructions and also perform this work. But you will learn a great deal just by reading our explanation of this work. Using any indirectly-heated cathode type triode, such as 6C5, or 76, we will connect the circuit as shown. The proper filament voltage will be applied to the terminals marked E_f . The other elements of the tube will be connected as illustrated.

Please check our description carefully against the drawing and make certain that you agree with our discussion. The plate (P) of the tube is connected to the source of plate voltage through a meter which shows the amount of plate current, I_p . Notice that the positive side of the battery is connected to the plate, while the negative side is returned to the cathode (K) of the tube. Now refer to the grid (G). Here also we have a battery, E_c , known as the C battery. The negative side is connected to the grid to keep it at a negative potential and prevent the grid from attracting electrons. The batteries are such that their voltage can be easily changed. For example, you may obtain any voltage from 0 to -28 volts on the grid, and from 0 to 500 volts on the plate.

The actual plate current of the tube will be indicated on the meter placed in the plate circuit. As you will recall from the explanation of the triode, the greater the plate voltage the greater will be the plate current. The grid also will have an effect on the

plate current. The greater *negative* voltage we place on the grid, the smaller the plate current will become. You can see, therefore, that the actual plate current will depend on the instant potential of both the plate and grid. The changes in the plate current cause the operation we need. These changes may be made by altering the plate voltage or by varying the grid voltage.

MAKING A GRAPH. To understand the operation of vacuum tubes, we will need a simple graph as an aid. We use some graph paper and let the vertical scale represent the plate current. You will notice that we marked each two divisions 4 milliamperes. This means that each division is 2 milliamperes. Starting with the zero base line, count up six spaces. Each space is 2, so six is equal to 12 milliamperes. For the time being, ignore the curves drawn in the center, but place a dot with a pencil anywhere in the graph. Follow straight to the left with your eye and read the current in milliamperes. If your dot leads you between two values of plate current, estimate by guessing the approximate value of the plate current. Select a few other points and be sure you can read the value of current which corresponds to the position of these points.

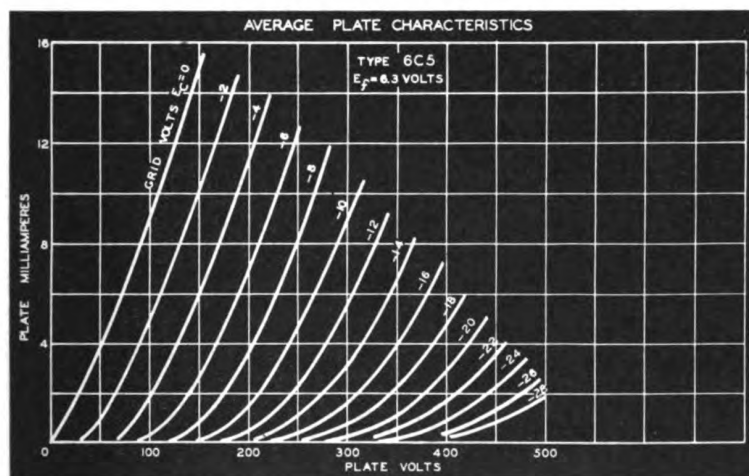


Figure 122. The family of curves obtained by carrying out an experiment similar to the one described in the text. Such average plate characteristics are known as the E_p - I_p curves.

The horizontal scale is used to indicate plate voltage. Here we also start with zero, but each division stands for 50 volts. Is that right? Go back to your dots, and by running your sight straight down, you will be able to read the voltage. You can see that each dot, or point, corresponds to one value of plate current and one value of plate voltage. We have selected a graph with a maximum current 16 ma. and maximum voltage of 500, because the tube we will consider is operated with less than 500 volts, and the plate current never rises above 16 milliamperes.

PLATE CHARACTERISTIC CURVES. Now we shall find out how the curves were obtained. First we will set the grid voltage battery at a fixed value. Let us make this voltage 0 volts, although usually tubes are operated with negative values on the grid. Now when we performed this experiment, we first reduced the plate battery

CHARACTERISTIC CURVES

It takes quite a bit of negative voltage on the control grid to completely eliminate (reduce to zero) the plate current.

You may review about graphs and how they are made. Refer to pages 25 and 26.

Each division is ordinarily marked with the number of units that will be convenient to make the maximum values required fit the available space.

The curves for other triodes may be similar, but will not be exactly the same.

Since you will refer to plate characteristic curves from time to time in your radio and electronic work, be sure that you are able to read the values indicated by the curves or any point lying in the graph.

USING E_p - I_p CHART DATA

If you are performing the actual experiment, the values you may obtain with the different voltages may not be exactly the same. But you will obtain curves which are similar in general appearance.

The student must follow this explanation with great care. Do the things the text suggests. The balance of this page will tell you how the amplification of a vacuum tube is computed.

The plate current change must be small and must be the same when considering the plate and grid voltages. However, it need not be any special value; 1 ma. used in the example was convenient.

The pages following present essential data on all receiving type vacuum tubes. The use of these data will be given a little later; now you may simply jump over to page 109, where the material on the amplification factor is continued.

to zero also, and found the plate current was also zero. So we went to the graph and marked the point which indicates plate current, $I_p = 0$, plate voltage, $E_p = 0$. This point is right in the lower left hand corner of the graph. Place a mark there.

Now we raised the plate voltage, E_p , to 50 volts. The meter showed that we had 4 ma. of plate current I_p . Mark the point where 50 volts crosses 4 ma.

We continued with our experiment, raising the plate voltage to 100 volts. The plate current was 9 ma. See if you can find this point. We also tried $E_p = 150$, and found $I_p = 15$ ma. Now we have three points, and by connecting them with a curved line, we obtain the curve marked as corresponding to "Grid Volts $E_c = 0$," since that was the value of grid voltage.

After this, we repeat the experiment with a slightly different value of grid voltage. Let us say, we use $E_c = -2$ volts. Again we obtain several points and connect them with a curved line. We find we get a curve almost the same as before, but moved over a little to the right.

This experiment was performed a great many times for various values of grid voltage, and the curves shown were obtained. These curves collectively are known as plate characteristic curves. They are useful for finding the operating details of the tube. Curves of this type have been made for all commercial vacuum tubes and many are included in tube manuals*.

AMPLIFICATION FACTOR. A plate voltage change will produce a change in plate current. Let us say we operate the tube with $E_c = -6$, and 200 volts on the plate. You can see from the graph that the plate current will be 7 ma. Find this value before going on.

If we keep E_c at the same value, how much must we increase the plate voltage to increase the plate current 1 ma., to total 8 ma.? Go back to the graph. Stick to the curve which represents grid voltage -6 . Find the place where the line from 8 ma. crosses this curve. From this point of intersection, follow down and read the plate voltage. Do you agree that it is about 210 volts? About 10 volts more than before. We have just learned that a 10 volt change in plate voltage produces a change of 1 ma. in plate current.

Let us go back to the original conditions; $E_c = -6$, $E_p = 200$. How much of a grid voltage change will be needed to produce a change of 1 ma., as before. This change makes $I_p = 8$, keeps E_p at 200, find the intersection of these two. There is no curve right through this intersection, but the curve to the left is for grid voltage of minus 4, the one to the right of this point is for minus 6 volts. By careful estimating, you can say that if a curve for $E_c = 5\frac{1}{2}$ negative volts be constructed, it would pass right through the point we are considering. Five and one-half volts is $\frac{1}{2}$ volt less than the original, and this $\frac{1}{2}$ volt also produces a change of 1 ma. in current just like 10 volts of plate voltage.

It is strange and interesting that $\frac{1}{2}$ volt of grid voltage will do the same as 10 volts of plate voltage, but this is just what permits a tube to amplify. The amplification factor, called mu and written as the Greek letter μ , is for practical purposes,

$$\mu = \frac{\text{Change in } E_p}{\text{Change in } E_g} \quad \text{both changes}$$

*A tube manual is a valuable aid to a radio repair man. Manuals of this type are issued by RCA Manufacturing Co., Inc., and by Sylvania Electric Products, Inc.

Sylvania RADIO TUBES



Characteristics

Type	Class	Base	Filament Rating		Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma.	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
			Volts	Amps.											
0A4G	Triode	4-V	....	....	Relay Tube	Peak Cathode Ma. = 100. D-C Cathode Ma. = 25 Max. Starter Anode Drop = 60 V. Approx. Anode Drop = 70 V. Approx.									
0Z4, 0Z4G	Duodiode	4-R	....	....	F-W Rect.	300 A-C Volts Per Plate, RMS, 75 Ma. Max. 30 Ma. Min. Output Current.									
01A	Triode	4-D	5.0	0.25	Amplifier	90 135	4.5 9.0	..... .....	2.5 3.0	..... .....	11,000 10,000	725 800	8.0 8.0	.....	.....
1A4P	Pentode	4-M	2.0	0.06	R-F Amp.	135 180	3.0 3.0	67.5 67.5	2.2 2.3	0.9 0.8	1 Meg. 1 Meg.	625 725	.....	.....	.....
1A4T	Tetrode	4-K	2.0	0.06	R-F Amp.	135 180	3.0 3.0	67.5 67.5	2.2 2.2	0.7 0.7	350,000 600,000	625 650	.....	.....	.....
1A5GT/G	Pentode	6-X	1.4	0.05	Power Amp.	85 90	4.5 4.5	85 90	3.5 4.0	0.7 0.8	300,000 300,000	800 850	.....	25,000 25,000	100 115
1A6	Heptode	6-L	2.0	0.06	Converter	135 180	3.0 3.0	67.5 67.5	1.8 1.5	2.1 2.0	400,000 500,000	275A 300A	(G ₂ = 135 V. □ Max. 2.0 Ma.) (G ₂ = 180 V. □ Max. 2.5 Ma.) (G ₂ = 90 V. Max. 1.2 Ma.)		
1A7G	Heptode	7-Z	1.4	0.05	Converter	90	0.0	45	0.55	0.60	600,000	250A			
1A7GT	Heptode	7-Z	1.4	0.05	Converter	Characteristics Same as Type 1A7G.									
1B4P	Pentode	4-M	2.0	0.06	R-F Amp.	135 180	3.0 3.0	67.5 67.5	1.6 1.7	0.7 0.6	1.5 Meg. ‡ 1.5 Meg. ‡	560 650	.....	.....	.....
1B5/255	Duodiode Tri.	6-M	2.0	0.06	Detector	135	3.0	.....	0.8	.....	35,000	575	20	.....	.....
1B7G	Heptode	7-Z	1.4	0.10	Converter	90	0.0	45	1.5	1.3	350,000	350A	(G ₂ = 90 V., 1.6 Ma.)		
1B7GT	Heptode	7-Z	1.4	0.10	Converter	Characteristics Same as Type 1B7G.									
1C5GT/G	Pentode	6-X	1.4	0.10	Power Amp.	83 90	7.0 7.5	83 90	7.0 7.5	1.6 1.6	110,000 115,000	1,500 1,550	165 180	9,000 8,000	200 240
1C6	Heptode	6-L	2.0	0.12	Converter	135 180	3.0 3.0	67.5 67.5	1.3 1.5	2.5 2.0	600,000 700,000	300A 325A	(G ₂ = 135 V. □ Max. 3.1 Ma.) (G ₂ = 180 V. □ Max. 4.0 Ma.)		
1C7G	Heptode	7-Z	2.0	0.12	Converter	135 180	3.0 3.0	67.5 67.5	1.3 1.5	2.5 2.0	600,000 700,000	300A 325A	(G ₂ = 135 V. □ Max. 3.1 Ma.) (G ₂ = 180 V. □ Max. 4.0 Ma.)		
1D5GP	Pentode	5-Y	2.0	0.06	R-F Amp.	135 180	3.0 3.0	67.5 67.5	2.2 2.3	0.9 0.8	1 Meg. 1 Meg.	625 725	.....	.....	.....
1D5GT	Tetrode	5-R	2.0	0.06	R-F Amp.	135 180	3.0 3.0	67.5 67.5	2.2 2.2	0.7 0.7	350,000 600,000	625 650	.....	.....	.....
1D7G	Heptode	7-Z	2.0	0.06	Converter	135 180	3.0 3.0	67.5 67.5	1.8 1.5	2.1 2.0	400,000 500,000	275A 300A	(G ₂ = 135 V. □ Max., 2.0 Ma.) (G ₂ = 180 V. □ Max., 2.5 Ma.)		
1E4G	Triode	5-S	1.4	0.05	Amplifier	90 90	0.0 3.0	..... .....	4.5 1.5	..... .....	11,000 17,000	1,325 825	14.5 14	.....	.....
1E5GP	Pentode	5-Y	2.0	0.06	R-F Amp.	135 180	3.0 3.0	67.5 67.5	1.6 1.7	0.7 0.6	1.5 Meg. ‡ 1.5 Meg. ‡	560 650	.....	.....	.....
1E7G	Duo. Pentode	8-C	2.0	0.24	Power Amp.	135	7.5	135	7.0 ‡	2.0 ‡	220,000	1,600	350	24,000 ‡	575
1F4	Pentode	5-K	2.0	0.12	Power Amp.	135	4.5	135	8.0	2.4	200,000	1,700	.....	16,000	310
1F5G	Pentode	6-X	2.0	0.12	Power Amp.	135	4.5	135	8.0	2.4	200,000	1,700	.....	16,000	310
1F6	Duodi. Pent.	6-W	2.0	0.06	R-F or I-F A-F Amp.	180 135*	1.5 2.0	67.5	2.2	0.7 1 Meg.	1 Meg. 650	.....	.....	.....	.....
1F7G	Duodi. Pent.	7-AD	2.0	0.06	R-F or I-F A-F Amp.	180 135*	1.5 2.0	67.5	2.2	0.7 1 Meg.	1 Meg. 650	.....	.....	.....	.....
1G4GT/G	Triode	5-S	1.4	0.05	Amplifier	90	6.0	.....	2.3	.....	10,700	825	8.8	.....	.....
1G5G	Pentode	6-X	2.0	0.12	Power Amp.	90	6.0	90	8.5	2.5	133,000 ‡	1,500	.....	8,500	250
1G6GT/G	Duodiode	7-AB	1.4	0.10	Power Amp. Class B	90 90	0.0 0.0	..... .....	1.0 ‡ 1.0 ‡	.....	45,000 ‡	675	30	(Each Triode Class A) 12,000 ‡	
1H4G	Triode	5-S	2.0	0.06	Det. Amp.	90 135 180	4.5 9.0 13.5	..... ..... .....	2.5 3.0 3.1	..... ..... .....	11,000 10,300 10,300	850 900 900	9.3 9.3 9.3	.....	.....
1H5G, GT	Diode-Triode	5-Z	1.4	0.05	Det., Amp.	90	0.0	.....	0.15	.....	240,000	275	65	.....	.....
1H6G	Duodiode Tri.	7-AA	2.0	0.06	Det., Amp.	135	3.0	.....	0.8	.....	35,000	575	20	.....	.....
1J5G	Pentode	6-X	2.0	0.12	Power Amp.	135	16.5	135	7.0	2.0	125,000	1,000	125	13,500	575
1J6G	Duodiode	7-AB	2.0	0.24	Power Amp.	Characteristics Same as Type 1J9.									
1LA4	Pentode	5-AD	1.4	0.05	Power Amp.	85 90	4.5 4.5	85 90	3.5 4.0	0.7 0.8	300,000 300,000	800 850	.....	25,000 25,000	100 115
1LA6	Heptode	7-AK	1.4	0.05	Converter	90	0.0	45	0.55	0.6	750,000	250A	(G ₂ = 90 V. Max., 1.2 Ma.)		
1LB4	Pentode	5-AD	1.4	0.05	Power Amp.	45 67.5 90	4.5 6.0 9.0	45 67.5 90	1.6 3.8 5.0	0.3* 0.8 1.0	300,000 200,000 200,000	650 875 925	.....	20,000 16,000 12,000	35 100 200
1LC5	Pentode	7-AO	1.4	0.05	Amplifier	45 90	0.0 0.0	45 45	1.1 1.5	0.25 0.20	700,000 1.5 Meg.	750 775	.....	.....	.....
1LC6	Heptode	7-AK	1.4	0.05	Converter	45 90	0.0 0.0	35 35	0.7 0.75	0.75 0.7	300,000 650,000	275A 250A	(G ₂ = 45 V. Max., 1.4 Ma.) (G ₂ = 45 V. Max., 1.4 Ma.)		
1LD5	Diode Pent.	6-AX	1.4	0.05	Amplifier	45 90	0.0 0.0	45 45	0.55 0.6	0.12 0.1	900,000 750,000	550 575	.....	.....	.....
1LE3	Triode	4-AA	1.4	0.05	Amplifier	90 90	0.0 3.0	..... .....	4.5 1.4	..... .....	11,200 19,000	1,300 760	14.5 14.5	.....	.....
1LH4	Diode-Tri.	5-AG	1.4	0.05	Amplifier	90	0.0	.....	0.15	.....	240,000	275	65	.....	.....
1LN5	Pentode	7-AO	1.4	0.05	Amplifier	90	0.0	90	1.6	0.35	1.1 Meg.	800	.....	.....	.....
1N5G, GT	Pentode	5-Y	1.4	0.05	R-F Amp.	90	0.0	90	1.2	0.3	1.5 Meg. ‡	750	.....	.....	.....
1N6G	Diode Pent.	7-AM	1.4	0.05	Power Amp.	90	4.5	90	3.4	0.7	300,000 ‡	800	.....	25,000	100
1P5G, GT	Pentode	5-Y	1.4	0.05	Amplifier	90	0.0	90	2.3	0.7	800,000	750	.....	.....	.....
1Q5GT/G	Tetrode	6-AF	1.4	0.10	Power Amp.	90	4.5	90	9.5	1.3	.....	2,200	.....	8,000	270
1R5	Heptode	7-AT	1.4	0.05	Converter	45 90	0.0 0.0	45 67.5	0.7 1.7	1.9 3.0	600,000 ‡ 500,000 ‡	235A 300A	.....	.....	.....
1S4	Pentode	7-AV	1.4	0.1	Power Amp.	45 90	4.5 7.0	45 67.5	3.8 ‡ 7.4 ‡	0.8 ‡ 1.4 ‡	100,000 ‡ 100,000 ‡	1,250 1,575	.....	8,000 8,000	65 270
1S5	Diode Pent.	6-AU	1.4	0.05	Amplifier	67.5	0.0	67.5	1.6	0.4	600,000	625	.....	.....	.....
1T4	Pentode	6-AR	1.4	0.05	R-F Amp.	45 90	0.0 0.0	45 67.5	1.9 3.7	0.7 1.25	350,000 500,000	700 900	.....	.....	.....
1T5GT	Tetrode	6-AF	1.4	0.05	Power Amp.	90	6.0	90	6.5	1.4	.....	1,150	.....	14,000	170
1V	Diode	4-G	6.3	0.30	H-W Rect.	325 A-C Volts Per Plate, RMS, 45 Ma. Output Current. Condenser Input to Filter.									
2A3	Triode	4-D	2.5	2.50	Power Amp. Class AB ₁	250 300	45.0 62.0	..... .....	60.0 40.0 per Tube, Push Pull, Fixed Bias	..... .....	800 5,250	.....	4.2	2,500 3,000 ‡	3,500 15,000

*Applied through 250,000 ohms.
†Per Tube or Section—No Signal.
‡Plate and Target Supply Voltage.

**Triode Operation.
††Applied through 200,000 ohms.
‡‡With Average Power Input of 320 Mw.

‡Pentode Operation.
†††For two tubes with 40 volts RMS applied to each grid.
‡‡‡Grid to Grid.

‡Plate to Plate.
‡‡Applied through 20,000 ohms.

‡Approximate.
‡‡Conversion Conductance
150 Volts RMS applied to two grids.

Type	Class	Base	Filament Rating		Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma.	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milli-watts
			Volts	Amps.											
2A4G	Triode	5-S	2.5	2.50	Relay Tube	Instantaneous Forward or Inverse Anode Volts = 200. Peak Anode Amps. = 1.25. Average Anode Current = 0.1 Amp. Max. Averaging Time = 45 Seconds. Cold Starting Time = 2 Seconds.									
2A5	Pentode	6-B	2.5	1.75	Power Amp.	Characteristics Same as Type 6F6G.									
2A6	Duodiode Tri.	6-G	2.5	0.80	Det. Amp.	250	2.0	.....	0.9	.....	91,000	1,100	100	.....	.....
2A7, 2A7S	Heptode	7-C	2.5	0.80	Converter	Characteristics Same as Type 6A7.									
2B7, 2B7S	Duodi. Pent.	7-D	2.5	0.80	R-F or I-F	Characteristics Same as Type 6B7.									
2E5	Triode	6-R	2.5	0.80	Indicator	Characteristics Same as Type 6E5.									
2S/4S	Duodiode	5-D	2.5	1.35	Detector	The Two Diode Plates each Draw Approximately 40.0 Ma. with 50 Volts D.C. on the Plates.									
2W3	Diode	4-X	2.5	1.50	H-W Rect.	350 A-C Volts Per Plate, RMS, 55 Ma. Output Current. Condenser Input to Filter.									
2X2/879	Diode	4-AB	2.5	1.75	H-W Rect.	4,500 A-C Volts Per Plate, RMS, 7.5 Ma. Output Current. Condenser Input to Filter.									
2Z2/G84	Diode	4-B	2.5	1.50	H-W Rect.	350 A-C Volts Per Plate, RMS, 50 Ma. Output Current.									
3A8GT	Diode Tri.-Pent.	8-AS	1.4	0.10	Tri.-Amp.	90	0.0	.....	0.15	.....	240,000	275	.....	.....	.....
			2.8	0.05	Pent.-Amp.	90	0.0	90	1.20	0.3	600,000	750	.....	.....	.....
3Q5GT/G	Tetrode (Series Fil. Oper.)	7-AP	1.4	0.10	Power Amp.	Characteristics Same as Type 3LF4.									
			2.8	0.05	Power Amp.	90	7.0	67.5	7.4	1.4	100,000	1,575	.....	8,000	270
3S4	Tetrode (Series Fil. Oper.)	7-BA	1.4	0.10	Power Amp.	90	7.0	67.5	6.1	1.1	100,000	1,425	.....	8,000	235
5U4G	Duodiode	5-T	5.0	3.00	F-W Rect.	450 A-C Volts Per Plate, RMS, 225 Ma. Output Current. Condenser Input to Filter.									
5V4G	Duodiode	5-L	5.0	2.00	F-W Rect.	375 A-C Volts Per Plate, RMS, 175 Ma. Output Current. Condenser Input to Filter.									
5W4GT/G	Duodiode	5-T	5.0	1.50	F-W Rect.	350 A-C Volts Per Plate, RMS, 110 Ma. Output Current. Condenser Input to Filter.									
5X4G	Duodiode	5-Q	5.0	3.00	F-W Rect.	450 A-C Volts Per Plate, RMS, 225 Ma. Output Current. Condenser Input to Filter.									
5Y3G	Duodiode	5-T	5.0	2.00	F-W Rect.	350 A-C Volts Per Plate, RMS, 125 Ma. Output Current. Condenser Input to Filter. Choke Input to Filter.									
5Y4G	Duodiode	5-Q	5.0	2.00	F-W Rect.	Characteristics Same as Type 5Y3G.									
5Z3	Duodiode	4-C	5.0	3.00	F-W Rect.	450 A-C Volts Per Plate, RMS, 225 Ma. Output Current. Condenser Input to Filter.									
5Z4	Duodiode	5-L	5.0	2.00	F-W Rect.	350 A-C Volts Per Plate, RMS, 125 Ma. Output Current. Condenser Input to Filter.									
6A3	Triode	4-D	6.3	1.00	Power Amp.	250	45.0	.....	60.0	.....	800	5,250	4.2	2,500	3,200
						325	68.0	.....	40.0#	.....	.....	.....	.....	3,000#	15,000
						325	.....	.....	40.0#	.....	.....	.....	.....	5,000#	10,000
6A4/LA	Pentode	5-B	6.3	0.30	Power Amp.	135	9.0	135	13.0	2.8	52,600	2,100	150	9,500	700
						180	12.0	180	22.0	3.9	60,000	2,500	150	8,000	1,500
6A5G	Triode	6-T	6.3	1.25	Power Amp. P.P. AB ₁ Amp	250	45.0	.....	60.0	.....	800	5,250	4.2	2,500	3,750
						325	68.0	.....	40.0	.....	.....	.....	.....	3,000#	15,000
6A6	Duodiode	7-B	6.3	0.80	Power Amp. Driver Driver	300	0.0	.....	17.5	.....	Per Plate, Class B Operation, Zero Signal	.....	.....	10,000#	10,000
						250	5.0	.....	6.0	.....	11,300	3,100	35	(Class A Driver)	.....
						294	6.0	.....	7.0	.....	11,000	3,200	35	(Class A Driver)	.....
6A7, 6A7S	Heptode	7-C	6.3	0.30	Converter	Characteristics Same as Type 6A8G, Except Capacitances.									
6A8	Heptode	8-A	6.3	0.30	Converter	Characteristics Same as Type 6A8G, Except Capacitances.									
6A8G, GT	Heptode	8-A	6.3	0.30	Converter	100	1.5	50	1.1	1.3	600,000	360A	(G ₂ = 100 V., 2.0 Ma.)	.....	.....
						250	3.0	100	3.5	2.7	360,000	550A	(G ₂ = 250 V., Max., 4.0 Ma.)	.....	.....
6AB5/6N5	Triode	6-R	6.3	0.15	Indicator	135# (Series Plate Resistor 0.25 Meg., Target Current 2.0 Ma., Grid Bias - 10 for 0° Shadow.)									
6AB7/1853	Pentode	8-N	6.3	0.45	Amplifier	300	3.0	200	12.5	3.2	700,000#	5,000	3,500#	.....	.....
6AC5GT/G	Triode	6-Q	6.3	0.40	Power Amp.	250	+13	.....	32.0	.....	36,700	3,400	125	7,000	3,700
						250	(Bias From 76 Driver)	.....	32.0	.....	(Class A ₁ , One Tube, Dynamic Coupled)	.....	.....	10,000#	8,000
						250	0.0	.....	2.5#	.....	(Class B, Two Tubes)	.....	.....	.....	.....
6AC7/1852	Pentode	8-N	6.3	0.45	Amplifier	300	.....	150	10.0	2.5	750,000#	9,000	6,750#	Bias Res. = 160 ohms.	.....
6AD6G	Duodiode	7-AG	6.3	0.15	Indicator	100# (Ray Control Volts = 45 Approx. For 0° Shadow, Approx. - 23 Volts for 135° Shadow.)									
						150# (Ray Control Volts = 75 Approx. For 0° Shadow, Approx. - 50 Volts for 135° Shadow.)									
6AD7G	Tri. Pentode	8-AY	6.3	0.85	Triode Amp. Pent. Amp.	250	25.0	.....	4.0	.....	19,000#	325	6	7,000	3,200
						250	16.5	250	34.0	6.5	80,000#	2,500	.....	.....	.....
6AE3GT/G	Triode	6-Q	6.3	0.30	Amplifier	95	15	.....	7.0	.....	3,500	1,200	4.2	.....	.....
6AE6G	Duo Plate Triode	7-AH	6.3	0.15	Remote Cut-Off Sharp Cut-Off	250	1.5	.....	6.5	.....	2,500	1,000	25	.....	.....
						250	35.0	.....	0.01	.....	.....	.....	.....	.....	.....
						250	1.5	.....	4.5	.....	3,500	950	33	.....	.....
						250	9.5	.....	0.01	.....	.....	.....	.....	.....	.....
6AE7GT	Duodiode	7-AX	6.3	0.50	Amplifier	250	13.5	.....	10.0	.....	4,650	3,000	14	.....	.....
						(Driver for P.P. 6AC5GT = 250 V., 10 Ma., 6AC5GT Plate Ma. = 64. Output 9.5 Watts with 10,000 Ohms Load, Bias Developed in Circuit.)									
6AF5G	Triode	6-Q	6.3	0.30	Amplifier	180	18.0	.....	7.0	.....	4,900	1,500	7.4	.....	.....
6AF6G	Duodiode	7-AG	6.3	0.15	Indicator	100# (Ray Control Volts = Approx. 60 for 0° Shadow, Approx. Zero Volt for 100° Shadow.)									
						135# (Ray Control Volts = Approx. 81 for 0° Shadow, Approx. Zero Volt for 100° Shadow.)									
6AG7	Pentode	8-Y	6.3	0.65	Amplifier	300	10.5	300	25.0	6.5	100,000	7,700	.....	.....	.....
6B4G	Triode	5-S	6.3	1.00	Power Amp.	Characteristics Same as Type 6A3.									
6B5	Duodiode	6-AS	6.3	0.80	Power Amp.	Characteristics Same as Type 6N6G.									
6B7, 6B7S	Duodi. Pent.	7-D	6.3	0.30	R-F or I-F Amplifier	100	3.0	100	5.8	1.7	300,000	950	.....	.....	.....
						180	3.0	75.0	3.4	0.9	1 Meg.	840	.....	.....	.....
						250	3.0	100	6.0	1.5	800,000	1,000	.....	.....	.....
						250	4.5	50.0	0.65	.....	.....	.....	.....	.....	.....
						250	3.0	125	10.0	2.3	600,000	1,325	.....	.....	.....
6B8	Duodi. Pent.	8-E	6.3	0.30	R-F or I-F	Characteristics Same as Type 6B7.									
6B8G	Duodi. Pent.	8-E	6.3	0.30	R-F or I-F	Characteristics Same as Type 6B7.									
6C5GT/G	Triode	6-Q	6.3	0.30	Amplifier	250	8.0	.....	8.0	.....	10,000	2,000	20	.....	.....
6C6	Pentode	6-F	6.3	0.30	Amplifier	100	3.0	100	2.0	0.5	1 Meg.	1,185	.....	.....	.....
						250	3.0	100	2.0	0.5	1 Meg. +	1,225	.....	.....	.....
6C7	Duodiode Tri.	7-G	6.3	0.30	Det. Amp.	250	9.0	.....	4.5	.....	16,000	1,250	20	.....	.....
6C8G	Duodiode	8-G	6.3	0.30	Amplifier Inverter	250	4.5	.....	3.2	.....	22,500	1,600	36	(One Section)	.....
						250	3.0	.....	.....	.....	Plate Load 100,000 Ohms, Self-Bias Resistor 1500 Ohms, Voltage Amplification 48.	.....	.....	.....	.....
						Output Volts 80, RMS, for Inverter Service.									
6D6	Pentode	6-F	6.3	0.30	Amplifier	100	3.0	100	8.0	2.2	250,000	1,500	.....	.....	.....
						250	3.0	100	8.2	2.0	800,000	1,600	.....	.....	.....
6D7	Pentode	7-H	6.3	0.30	Amplifier	Characteristics Same as Type 6C6.									
6D8G	Heptode	8-A	6.3	0.15	Converter	135	3.0	62.5	1.5	1.7	600,000	325A	(G ₂ = 135 V., 1.8 Ma.)	.....	.....
						250	3.0	100	3.5	2.6	400,000	550A	(G ₂ = 250 V., 4.5 Ma.)	.....	.....
6E5	Triode	6-R	6.3	0.30	Indicator	100# (Series Plate Resistor 0.5 Meg. Target Current 1.0 Ma. Grid Bias - 3.3 for 0° Shadow.)									
						250# (Series Plate Resistor 1.0 Meg. Target Current 4.0 Ma. Grid Bias - 8.0 for 0° Shadow.)									

*Applied through 250,000 ohms.
†Per Tube or Section—No Signal.
‡Plate and Target Supply Voltage

**Triode Operation.
††Applied through 200,000 ohms.
‡‡With Average Power Input of 320 Mw. Grid to Grid.

‡Pentode Operation.
†††For two tubes with 40 volts RMS applied to each grid.
‡‡‡Applied through 20,000 ohms.

‡‡‡Approximate.
‡‡‡‡Conversion Conductance
‡‡‡‡‡150 Volts RMS applied to two grids.

Type	Class	Base	Filament Rating		Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma.	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milli-watts
			Volts	Amps.											
6	Duotriode	7-B	6.3	0.60	Power Amp. (1 Section)	180 250	20.0 27.5	..... .....	11.5 18.0	..... .....	4,300 3,500	1,400 1,700	6.0 6.0	15,000* 14,000*	750 1,600
7	Pentode	7-H	6.3	0.30	Amplifier	Characteristics Same as Type 6D6.									
5, G, GT	Triode	5-M	6.3	0.30	Amplifier	250	2.0	.....	0.9	.....	66,000	1,500	100	.....	.....
6, 6F6G	Pentode	7-S	6.3	0.70	Power Amp.	250 285 315 375	16.5 20.0 24.0 26.0	250 285 285 250	34.0 38.0 62.0 34.0	6.5 7.0 12.0 5.0	80,000 78,000 (Current & Output for Two Tubes) (Current & Output for Two Tubes)	2,500 2,550	.....	7,000 7,000 10,000* 10,000*	3,200 4,800 11,000 18,000
7, 6F7S	Pent.-Triode	7-E	6.3	0.30	Pent. Amp. Pent. Amp. Triode Amp.	100 250 100	3.0 3.0 3.0	100 100	6.3 6.5 3.5	1.6 1.5	290,000 850,000 16,200	1,050 1,100 525	 8.5	Pentode Section Pentode Section Triode Section (One Section)	.....
8G	Duotriode	8-G	6.3	0.60	Amplifier Inverter	250 250	8.0 5.5	..... .....	9.0 .....	..... .....	7,700 (Plate Load 50,000 Ohms Per Plate, Self Bias Resistor 1,150 Ohms, Voltage Amplification 29, Output Volts 65, RMS, for Inverter Service.)	2,600	20	.....	.....
6G	Pentode	7-S	6.3	0.15	Power Amp.	135 180	6.0 9.0	135 180	11.5 15.0	2.0 2.5	170,000 175,000	2,100 2,300	.....	12,000 10,000	600 1,100
14GT	Diode	5-AF	6.3	0.15	Rectifier	100	.....	.....	4.0	.....	.....	.....	.....	.....	.....
16GT/G	Duodiode	7-Q	6.3	0.30	Rectifier	117 A-C Volts Per Plate, RMS, 4.0 Ma. Output Current.									
5GT/G	Triode	6-Q	6.3	0.30	Amplifier	250	8.0	.....	9.0	.....	7,700	2,600	20	.....	.....
7	Pentode	7-R	6.3	0.30	Amplifier	250	3.0	100	2.0	0.5	1.0 Meg. +	1,225	.....	.....	.....
7G, GT	Pentode	7-R	6.3	0.30	Amplifier	Characteristics Same as Type 6J7, Except Capacitances.									
3G	Tri.-Heptode	8-H	6.3	0.30	Mixer Oscillator	250 250	3.0 1.5	100	1.3 0.35	2.9	4.0 Meg. 78,000	290A 900	(Heptode Section) 70	250 Plate Supply Thru 20,000 Res., Grid Resistor 50,000, Grid Current 0.4 Ma., Plate Current 5.0 Ma. (Triode Section)	
5G	Triode	5-U	6.3	0.30	Amplifier	100 250	1.5 3.0	..... .....	0.35 1.10	..... .....	50,000	1,400	70 70	.....	.....
5GT	Triode	5-U	6.3	0.30	Amplifier	Characteristics Same as Type 6K5G, Except Capacitances.									
6GT/G	Pentode	7-S	6.3	0.40	Power Amp.	100 250 315	7.0 18.0 21.0	100 250 250	9.0 32.0 25.5	1.6 5.5 4.0	104,000 68,000 75,000	1,500 2,300 2,100	.....	12,000 7,600 9,000	350 3,400 4,500
7	Pentode	7-R	6.3	0.30	Amplifier	90 180 250	3.0 3.0 3.0	90.0 75.0 100	5.4 4.0 7.0	1.3 1.0 1.7	300,000 1 Meg. 800,000	1,275 1,100 1,450	.....	.....	.....
7G, GT	Pentode	7-R	6.3	0.30	Amplifier	Characteristics Same as Type 6K7, Except Capacitances.									
8	Tri.-Hexode	8-K	6.3	0.30	Mixer Osc.	Characteristics Same as Type 6K8G, Except Capacitances.									
8G, GT	Tri.-Hexode	8-K	6.3	0.30	Mixer Oscillator	250 100	3.0	100	2.5	6.0	600,000	350A	(Hexode Section)	Grid Resistor 50,000 Plate Current 3.8 Ma., Conversion Conductance 3000 (Triode Section not Oscillating)	
5G	Triode	6-Q	6.3	0.15	Amplifier	100 250	3.0 9.0	..... .....	4.0 8.0	..... .....	10,000 9,000	1,500 1,900	15	.....	.....
6, 6L6G	Tetrode	7-AC	6.3	0.90	Power Amp. P.P. A ₁ Amp. P.P. A ₂ Amp. P.P. A ₃ Amp.	250 350 270 360 360	14.0 18.0 17.5 22.5 22.5	250 250 250 270 270	72.0 54.0 134.0 88.0 88.0	5.0 2.5 11.0 5.0 5.0	22,500 33,000 23,500	6,000 5,900 5,700	.....	2,500 4,200 5,000* 6,600* 3,800*	6,500 10,800 17,500 26,500 47,000
7	Heptode	7-T	6.3	0.30	Mixer Amplifier	250 250	6.0 3.0	150 100	3.3 5.3	9.2 6.5	1 Meg. + 600,000	350A 1,100	(G ₃ = Neg. 15 Volts) (G ₃ = Neg. 3.0 Volts)	.....	
7G	Heptode	7-T	6.3	0.30	Mixer-Amp.	Characteristics Same as Type 6L7, Except Capacitances.									
6G	Duotriode	7-AU	6.3	0.80	Power Amp.	300 300	0.0 0.0	(Input Section) (Output Section)	8.0 45.0	..... .....	24,000†	2,400	58	7,000	4,000
7, 6N7G	Duotriode	8-B	6.3	0.80	Power Amp. Driver Driver	300 250 294	0.0 5.0 6.0	..... ..... .....	17.5 Per Plate, Class B Operation, Zero Signal 6.0 7.0	..... ..... .....	11,300 11,000	3,100 3,200	35 35	8,000* (Class A Driver) (Class A Driver)	10,000
5GT/G	Triode	6-Q	6.3	0.30	Amplifier Detector	250 250	13.5 20.0†	..... .....	5.0	 (Plate Current to be adjusted to 0.2 Ma. with no Input Signal)	9,500	1,450	13.8	.....	.....
7G	Pent.-Triode	7-U	6.3	0.30	Amplifier	Characteristics Same as Type 6F7, Except Capacitances.									
7	Duodiode Tri.	7-V	6.3	0.30	Det.-Amp.	100 250	1.5 3.0	..... .....	0.35 1.1	..... .....	88,000 58,000	800 1,200	70 70	.....	.....
7G, GT	Duodiode Tri.	7-V	6.3	0.30	Det.-Amp.	Characteristics Same as Type 6Q7, Except Capacitances.									
7	Duodiode Tri.	7-V	6.3	0.30	Det.-Amp.	250	9.0	.....	9.5	.....	8,500	1,900	16	.....	.....
7G, GT	Duodiode Tri.	7-V	6.3	0.30	Detector	Characteristics Same as Type 6R7, Except Capacitances.									
7	Pentode	7-R	6.3	0.15	Amplifier	Characteristics Same as Type 6S7G, Except Capacitances.									
7G	Pentode	7-R	6.3	0.15	Amplifier	135 250	3.0 3.0	67.5 100	3.7 8.5	0.9 2.0	1 Meg.† 1 Meg.†	1,250 1,750	375 1,100	.....	.....
A7	Heptode	8-R	6.3	0.30	Converter	100 250	2.0 2.0	100 100	3.3 3.5	8.5 8.5	500,000† 1.0 Meg.†	425A 450A	.....	.....	.....
A7GT/G	Heptode	8-AD	6.3	0.30	Converter	Characteristics Same as Type 6SA7, Except Capacitances.									
C7	Duotriode	8-S	6.3	0.30	Amplifier	250	2.0	.....	2.0	.....	53,000	1,325	70	(Each Triode)	
D7GT	Pentode	8-N	6.3	0.30	Amplifier	100 250	2.0 2.0	100 100	5.7 6.0	2.0 1.9	250,000† 1.0 Meg.†	3,350 3,600	.....	.....	.....
F5	Triode	6-AB	6.3	0.30	Amplifier	250	2.0	.....	0.9	.....	66,000	1,500	100	.....	.....
F5GT	Triode	6-AB	6.3	0.30	Amplifier	Characteristics Same as Type 6SF5, Except Capacitances.									
J7	Pentode	8-N	6.3	0.30	Amplifier	100 250	3.0 3.0	100 100	2.9 3.0	0.9 0.8	700,000† 1.5 Meg.†	1,575 1,650	.....	.....	.....
J7GT	Pentode	8-N	6.3	0.30	Amplifier	Characteristics Same as Type 6SJ7, Except Capacitances.									
K7	Pentode	8-N	6.3	0.30	Amplifier	100 250	1.0 3.0	100 100	13.0 9.2	4.0 2.6	120,000† 800,000†	2,350 2,000	.....	.....	.....
K7GT/G	Pentode	8-N	6.3	0.30	Amplifier	Characteristics Same as Type 6SK7, Except Capacitances.									
Q7	Duodiode Tri.	8-Q	6.3	0.30	Det.-Amp.	250	2.0	.....	0.9	.....	91,000	1,100	100	.....	.....
Q7GT/G	Duodiode Tri.	8-Q	6.3	0.30	Det.-Amp.	Characteristics Same as Type 6SQ7, Except Capacitances.									
R7	Duodiode Tri.	8-Q	6.3	0.30	Det.-Amp.	250	9.0	.....	9.5	.....	8,500	1,900	16	.....	.....
7G	Duodiode Tri.	7-V	6.3	0.15	Det.-Amp.	100 250	1.5 3.0	..... .....	0.3 1.2	..... .....	95,000 62,000	680 1,050	65 65	.....	.....
15/6G5	Triode	6-R	6.3	0.30	Indicator	100‡ 250‡	(Series Plate Resistor 0.5 Meg., Target Current 1.0 Ma., Grid Bias -8.0 for 0° Shadow.) (Series Plate Resistor 1.0 Meg., Target Current 4.0 Ma., Grid Bias -22.0 for 0° Shadow.)								
16GT	Tetrode	7-AC	6.3	0.75	Power Amp.	110 200	10.5 14.0	110 135	44.0 55.0	4.0 3.0	10,000† 20,000†	5,600 6,200	.....	2,000 3,000	2,000 5,500
17G	Pentode	7-R	6.3	0.30	Amplifier	100 250	3.0 3.0	100 100	8.0 8.2	2.2 2.0	250,000 800,000	1,500 1,600	.....	.....	.....

Applied through 250,000 ohms.
††Applied through 200,000 ohms.
‡‡With Average Power Input of 320 Mw. Grid to Grid.

**Triode Operation.

†Pentode Operation.

‡Plate to Plate.

††Approximate.

‡‡Conversion Conductance

‡‡Applied through 200,000 ohms.

††For two tubes with 40 volts RMS applied to each grid.

□ Applied through 20,000 ohms.

Type	Class	Base	Filament Rating		Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma.	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milli-watts
			Volts	Amps.											
V6GT/G	Tetrode	7-AC	6.3	0.45	Power Amp.	Characteristics Same as Type 7C5.									
V7G	Duodiode Tri.	7-V	6.3	0.30	Det.-Amp.	135 180 250	10.5 13.5 20.0	..... ..... .....	3.7 6.0 8.0	..... ..... .....	11,000 8,500 7,500	750 975 1,100	8.3 8.3 8.3	25,000 20,000 20,000	75 160 350
V7G	Pentode	7-R	6.3	0.15	Amplifier	250	3.0	100	2.0	0.5	1.5 Meg.†	1,225	.....	.....	.....
V5GT/G	Duodiode	6-S	6.3	0.60	F-W Rect.	325 A-C Volts per Plate, RMS, 70 Ma. Output Current. Condenser Input to Filter. 450 A-C Volts per Plate, RMS, 70 Ma. Output Current. Choke Input to Filter.									
V5	Duodiode	6-J	6.3	0.80	F-W Rect.	350 A-C Volts per Plate, RMS, 50 Ma. Output Current.									
V6G	Tetrode	7-AC	6.3	1.25	Power Amp.	135 200 250	13.5 14.0 0.0	135 135	58.0 61.0 7.5†	3.5 2.2	9,300 18,300 (Class B Operation)	7,000 7,100 (Class B Operation)	..... ..... .....	2,000 2,600 14,000†	3,600 6,000 8,000
V7G	Duotriode	8-B	6.3	0.60	Power Amp.	180 250	0.0 0.0	..... .....	7.5† 10.5†	..... .....	(Class B Operation)		.....	7,000† 14,000†	5,500 8,000
VZ5	Duodiode	6-K	6.3 12.6	0.80 0.40	F-W Rect.	230 A-C Volts per Plate, RMS, 60 Ma. Output Current									
VZ5G	Duodiode	6-S	6.3	0.30	F-W Rect.	325 A-C Volts per Plate, RMS, 40 Ma. Output Current. Condenser Input to Filter.									
VZ7G	Duotriode	8-B	6.3	0.30	Power Amp.	135 180	0.0 0.0	..... .....	3.0† 4.2†	..... .....	(Class B Operation)		.....	9,000† 12,000†	2,500† 4,200†
V4A	Triode	5-AC	6.3	0.30	Amplifier	90 250	0.0 8.0	..... .....	10.0 9.0	..... .....	6,700 7,700	3,000 2,600	20 20	.....	.....
V4A	Tetrode	6-AA	6.3	0.75	Power Amp.	110 125	7.5 9.0	110 125	40.0 44.0	3.0 3.3	14,000 17,000	5,800 6,000	.....	2,500 2,700	1,500 2,200
V4A	Duodiode	7-AJ	6.3	0.15	Det.-Rect.	150 A-C Volts per Plate, RMS, 8 Ma. Output Current per Plate.									
V4A	Pentode	8-V	6.3	0.30	Amplifier	100 250	1.0 3.0	100 100	13.0 9.2	4.0 2.6	120,000† 800,000†	2,350 2,000	.....	.....	.....
V4A	Octode	8-U	6.3	0.15	Converter	100 250	3.0 3.0	75 100	1.8 3.0	2.7 3.2	650,000† 700,000†	375A 550A	(G2=100 V., 2.8 Ma.) (G2=250 V., 4.2 Ma.)		
V4B	Triode	5-AC	6.3	0.30	Amplifier	100 250	1.0 2.0	..... .....	0.4 0.9	..... .....	85,000 66,000	1,150 1,500	100 100	.....	.....
V4B	Pentode	6-AE	6.3	0.40	Power Amp.	100 250 315	7.0 18.0 21.0	100 250 250	9.0 32.0 25.5	1.6 5.5 4.0	104,000 68,000 75,000	1,500 2,300 2,100	.....	12,000 7,600 9,000	350 3,400 4,500
V4B	Duodiode Tri.	8-W	6.3	0.30	Amplifier	100 250	1.0 2.0	..... .....	0.4 0.9	..... .....	110,000 91,000	900 1,100	100 100	.....	.....
V4B	Pentode	8-V	6.3	0.15	Amplifier	100 250	3.0 3.0	100 100	8.2 8.5	1.8 1.7	300,000 750,000	1,675 1,750	.....	.....	.....
V4B	Heptode	8-X	6.3	0.30	Converter	100 250	1.5 3.0	50 100	1.1 3.5	1.3 2.7	600,000 360,000	360A 550A	(G2=100 V., 2.0 Ma.) (G2=250 V., 4.0 Ma.)		
V4C5	Tetrode	6-AA	6.3	0.45	Power Amp.	180 250 315	8.5 12.5 13.0	180 250 225	29.0 45.0 34.0	3.0 4.5 2.2	58,000 52,000 77,000	3,700 4,100 3,750	.....	5,500 5,000 8,500	2,000 4,500 5,500
V4C5					Class AB ₁	250 285	15.0 18.0	250 285	70.0 70.0	5.0 4.0	(Class AB ₁ , Two Tubes) (Class AB ₁ , Two Tubes)		.....	10,000† 8,000†	10,000 14,000
V4C6	Duodiode Tri.	8-W	6.3	0.15	Amplifier	100 250	0.0 1.0	..... .....	1.0 1.3	..... .....	100,000 100,000	850 1,000	85 100	.....	.....
V4C7	Pentode	8-V	6.3	0.15	Amplifier	100 250	3.0 3.0	100 100	1.8 2.0	0.4 0.5	1.2 Meg.† 2.0 Meg.†	1,225 1,300	.....	.....	.....
V4E6	Duodiode Tri.	8-W	6.3	0.30	Amplifier	250	9.0	.....	9.5	.....	8,500	1,900	16	.....	.....
V4E7	Duodi. Pent.	8-AE	6.3	0.30	Amplifier	100 250	1.0 3.0	100 100	10.0 7.5	2.7 1.6	150,000† 700,000†	1,600 1,300	36 42.5	.....	.....
V4F7	Duotriode	8-AC	6.3	0.30	Amplifier	100 250	1.0 2.0	..... .....	0.65 2.3	..... .....	62,000† 44,000†	1,125 1,600	70 70	.....	.....
V4G7/1232	Pentode	8-V	6.3	0.45	Amplifier	250	2.0	100	6.0	2.0	800,000†	4,500	.....	.....	.....
V4H7	Pentode	8-V	6.3	0.30	Amplifier	100 250	1.0 2.5	100 150	8.2 9.5	3.3 3.5	250,000 800,000	3,800 3,800	.....	.....	.....
V4J7	Tri.-Hexode	8-BL	6.3	0.30	Hex. Mixer Tri. Osc.	100 250 100 250†	3.0 3.0 0.05 Meg. 0.05 Meg.	100 100	1.5 1.4 3.2 5.0	2.6 2.8	500,000 1.5 Meg. (Triode Grid Current 0.3 Ma.) (Triode Grid Current 0.4 Ma.)	280A 290A	.....	.....	.....
V4L7	Pentode	8-V	6.3	0.30	Amplifier	100 250	1.0 1.5	100 100	5.5 4.5	2.4 1.5	100,000† 1.0 Meg.	3,000 3,100	.....	.....	.....
V4N7	Duotriode	8-AC	6.3	0.60	Amplifier (One Unit)	90 250	0.0 8.0	..... .....	10.0 9.0	..... .....	6,700 7,700	3,000 2,600	20 20	.....	.....
V4Q7	Heptode	8-AL	6.3	0.30	Converter	100 250	2.0 2.0	100 100	3.3 3.5	8.5 8.5	500,000 1.0 Meg.	525A 550A	Osc. Grid Resistor 20,000. Osc. Grid Current 0.5 Ma.		
V4R7	Diode-Pent.	8-AE	6.3	0.30	Amplifier	100 250	1.0 1.0	100 100	5.5 5.7	2.2 2.1	350,000† 1.0 Meg.†	3,000 3,200	.....	.....	.....
V4S7	Tri.-Heptode	8-BL	6.3	0.30	Hep. Mixer Tri. Osc.	100 250 100 250†	2.0 2.0 0.05 Meg. 0.05 Meg.	100 100	1.9 1.8 3.0 5.0	3.0 3.0	500,000† 1.25 Meg.† (Triode Grid Current 0.3 Ma.) (Triode Grid Current 0.4 Ma.)	500A 525A	.....	.....	.....
V4V7	Pentode	8-V	6.3	0.45	Amplifier	300	.....	150	10.0	3.9	300,000	5,800 (Cath. Bias Resistor = 160 Ohms)	.....	.....	.....
V4W7	Pentode	8-BJ	6.3	0.45	Amplifier	Characteristics Same as Type 7V7, Except Capacitances.									
V4Y4	Duodiode	5-AB	6.3	0.50	F. W. Rect.	325 A-C Volts per Plate, RMS, 60 Ma. Output Current. Condenser Input to Filter. 450 A-C Volts per Plate, RMS, 60 Ma. Output Current. Choke Input to Filter.									
V4Z4	Duodiode	5-AB	6.3	0.90	F. W. Rect.	325 A-C Volts per Plate, RMS, 100 Ma. Output Current. Condenser Input to Filter. 450 A-C Volts per Plate, RMS, 100 Ma. Output Current. Choke Input to Filter.									
V4A0	Triode	4-D	7.5	1.25	Power Amp.	250 350 425	23.5 32.0 40.0	..... ..... .....	10.0 16.0 18.0	..... ..... .....	6,000 5,150 5,000	1,330 1,550 1,600	8.0 8.0 8.0	13,000 11,000 10,200	400 900 1,600
V4A	Triode	4-D	5.0	0.25	Det.-Amp.	90 135 180	4.5 9.0 13.5	..... ..... .....	5.0 6.2 7.7	..... ..... .....	5,400 5,100 4,700	1,575 1,650 1,800	8.5 8.5 8.5	5,000 9,000 10,650	35 130 285
V4A5	Pentode	7-F	12.6 6.3	0.30 0.60	Power Amp. Power Amp.	100 180	15.0 25.0	100 180	17.0 45.0	3.0 8.0	50,000† 35,000†	1,700 2,400	.....	4,500 3,300	800 3,400
V4A7	Diode-Pent.	7-K	12.6	0.30	Rectifier Amplifier	125 RMS 135	 13.5	 135	30.0 Max. 9.0	2.5	102,000	975	100	13,500	550
V4A8G, GT	Heptode	8-A	12.6	0.15	Converter	Characteristics Same as Type 6A8G.									
V4B8GT	Pentode Tri.	8-T	12.6	0.30	Pent. Amp. Tri.-Amp.	100 100	3.0 1.0	100	8.0 0.6	2.0	170,000 73,000	2,100	360 110	Pentode Section Triode Section	

Applied through 250,000 ohms.
Per Tube or Section—No Signal.
Plate and Target Supply Voltage.

††Triode Operation.

‡Applied through 200,000 ohms.

‡‡With Average Power Input of 320 Mw. Grid to Grid.

‡Pentode Operation.

††For two tubes with 40 volts RMS applied to each grid.

□Applied through 20,000 ohms.

†Plate to Plate.

†Approximate.

△Conversion Conductance
150 Volts RMS applied to two grids.

Type	Class	Base	Filament Rating		Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma.	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts	
			Volts	Amps.												
2C8	Pentode	8-E	12.6	0.15	R-F or I-F	Characteristics Same as Type 6B8.										
2F5GT	Triode	5-M	12.6	0.15	Amplifier	Characteristics Same as Type 6F5G.										
2J5GT	Triode	6-Q	12.6	0.15	Amplifier	Characteristics Same as Type 6J5GT/G.										
2J7GT	Pentode	7-R	12.6	0.15	Amplifier	Characteristics Same as Type 6J7G.										
2K7G, GT	Pentode	7-R	12.6	0.15	Amplifier	Characteristics Same as Type 6K7G.										
2K8	Tri.-Hexode	8-K	12.6	0.15	Converter	Characteristics Same as Type 6K8.										
2Q7G, GT	Duodiode-Tri.	7-V	12.6	0.15	Det.-Amp.	Characteristics Same as Type 6Q7G.										
2SA7	Heptode	8-R	12.6	0.15	Converter	Characteristics Same as Type 6SA7.										
2SA7GT/G	Heptode	8-AD	12.6	0.15	Converter	Characteristics Same as Type 6SA7GT/G.										
2SC7	Duotriode	8-S	12.6	0.15	Amplifier	Characteristics Same as Type 6SC7.										
2SF5, GT	Triode	6-AB	12.6	0.15	Amplifier	Characteristics Same as Type 6SF5.										
2SJ7	Pentode	8-N	12.6	0.15	Amplifier	Characteristics Same as Type 6SJ7.										
2SJ7GT	Pentode	8-N	12.6	0.15	Amplifier	Characteristics Same as Type 6SJ7, Except Capacitances.										
2SK7	Pentode	8-N	12.6	0.15	Amplifier	Characteristics Same as Type 6SK7.										
2SK7GT/G	Pentode	8-N	12.6	0.15	Amplifier	Characteristics Same as Type 6SK7GT/G.										
2SQ7	Duodiode Tri.	8-Q	12.6	0.15	Det.-Amp.	Characteristics Same as Type 6SQ7.										
2SQ7GT/G	Duodiode Tri.	8-Q	12.6	0.15	Det.-Amp.	Characteristics Same as Type 6SQ7GT/G.										
2SR7	Duodiode Tri.	8-Q	12.6	0.15	Det.-Amp.	Characteristics Same as Type 6SR7.										
2Z3	Diode	4-G	12.6	0.30	H-W Rect.	235 A-C Volts per Plate, RMS, 55 Ma. Output Current. Condenser Input to Filter.										
4A4	Triode	5-AC	12.6	0.15	Amplifier	90 250	0.0 8.0	..... .....	10.0 9.0	..... .....	6,700 7,700	3,000 2,600	20 20	..... .....	..... .....	
4A5	Tetrode	6-AA	12.6	0.15	Power Amp.	250	12.5	250	30.0	3.5	70,000†	3,000	.....	7,500	2,800	
4A7/12B7	Pentode	8-V	12.6	0.15	Amplifier	100 250	1.0 3.0	100 100	13.0 9.2	4.0 2.6	120,000† 800,000†	2,350 2,000	..... .....	..... .....	..... .....	
4B6	Duodiode Tri.	8-W	12.6	0.15	Det.-Amp.	100 250	1.0 2.0	..... .....	0.4 0.9	..... .....	110,000† 91,000	900 1,100	100 100	..... .....	..... .....	
4B8	Heptode	8-X	12.6	0.15	Converter	100 250	1.5 3.0	50.0 100	1.1 3.5	1.3 2.7	600,000 360,000	360A 550A	(G2=100V., 2.0 Ma.) (G2=250 V.□, 4.0 Ma.)			
4C5	Tetrode	6-AA	12.6	0.225	Power Amp.	Characteristics Same as Type 7C5.										
4C7	Pentode	8-V	12.6	0.15	Amplifier	100 250	1.0 3.0	100 100	5.7 2.2	1.8 0.7	325,000† 1.0 Meg.†	2,275 1,575	..... .....	..... .....	..... .....	
4E6	Duodiode Tri.	8-W	12.6	0.15	Amplifier	250	9.0	.....	9.5	.....	8,500	1,900	16	.....	.....	
4F7	Duotriode	8-AC	12.6	0.15	Amplifier	100 250	1.0 2.0	..... .....	0.65 2.3	..... .....	62,000† 44,000†	1,125 1,600	70 70	..... .....	..... .....	
4H7	Pentode	8-V	12.6	0.15	Amplifier	100 250	1.0 2.5	100 150	8.2 9.5	3.3 3.5	250,000† 800,000†	3,800 3,800	..... .....	..... .....	..... .....	
4J7	Tri. Hexode	8-AR	12.6	0.15	Mixer Osc.	Characteristics Same as Type 7J7.										
4N7	Duotriode	8-AC	12.6	0.30	Amplifier (One Unit)	90 250	0.0 8.0	..... .....	10.0 9.0	..... .....	6,700 7,700	3,000 2,600	20 20	..... .....	..... .....	
4Q7	Heptode	8-AL	12.6	0.15	Converter	100 250	2.0 2.0	100 100	3.3 3.5	8.5 8.5	500,000 1.0 Meg.	525A / Osc. Grid Resistor 20,000 550A / Osc. Grid Current 0.5 Ma.	..... .....	..... .....	..... .....	
4R7	Diode-Pent.	8-AE	12.6	0.15	Amplifier	100 250	1.0 1.0	100 100	5.5 5.7	2.2 2.1	350,000† 1.0 Meg.†	3,000 3,200	..... .....	..... .....	..... .....	
4S7	Tri. Heptode	8-BL	12.6	0.15	Mixer Osc.	Characteristics Same as Type 7S7.										
4W7	Pentode	8-BJ	12.6	0.225	Amplifier	Characteristics Same as Type 7V7, Except Capacitances.										
4Y4	Duodiode	5-AB	12.6	0.30	F. W. Rect.	325 A-C Volts per Plate, RMS, 70 Ma. Output Current. Condenser Input to Filter. 450 A-C Volts per Plate, RMS, 70 Ma. Output Current. Choke Input to Filter.										
5	Pentode	5-F	2.0	0.22	R-F Amp.	67.5 135	1.5 1.5	67.5 67.5	1.85 1.85	0.3 0.3	630,000 800,000	710 750	450 600	..... .....	..... .....	
5B6	Pentode	6-B	14.0	0.30	Power Amp.	Characteristics Same as Type 6F6G.										
5B9	Duotriode	6-C	2.0	0.26	Power Amp.	135 135 135	0.0 3.0 6.0	..... ..... .....	5.0 1.7 0.1	..... ..... .....	(Class B Operation) (Class B Operation) (Class B Operation)	..... ..... .....	10,000† 10,000† 10,000†	2,100 1,900 1,600	..... ..... .....	
6	Triode	4-D	3.3	0.132	Power Amp.	90 135	16.5 22.5	..... .....	2.8 6.0	..... .....	7,800 5,850	450 600	3.5 3.5	9,600 6,500	50 130	
6A4, 24S	Tetrode	4-K	3.3	0.132	R-F Amp.	135	1.5	67.5	3.7	1.3	250,000	500	125	.....	.....	
	Tetrode	5-E	2.5	1.75	R-F Amp.	180 250	3.0 3.0	90.0 90.0	4.0 4.0	1.7 1.7	400,000 600,000	1,000 1,050	400 630	..... .....	..... .....	
					Detector	250*	5.0†	20 to 45 (Plate Current to be adjusted to 0.1 Ma. with no Input Signal)								
6A6GT/G	Pentode	7-S	25.0	0.30	Power Amp.	95 135 160	15.0 20.0 18.0	95.0 135 120	20.0 37.0 33.0	4.0 8.0 6.5	45,000 35,000 42,000	2,000 2,450 2,375	..... ..... .....	4,500 4,000 5,000	900 2,000 2,200	
6A7GT/G	Diode-Pent.	8-F	25.0	0.30	H-W Rect. Power Amp.	117	A-C Volts per Plate, RMS, 75 Ma. Output Current.									
6AC5GT/G	Triode	6-Q	25.0	0.30	Power Amp. Coupled Amp	100 165	15.0	100	20.5 45.0	4.0	50,000 15,200	1,800 3,800	 58	4,500 2,000	770 2,000	
6B6G	Pentode	7-S	25.0	0.30	Power Amp.	105 200	16.0 23.0	105 135	48.0 62.0	2.0 1.8	15,500 18,000	4,800 5,000	..... .....	1,700 2,500	2,400 7,100	
6B8GT	Pentode Tri.	8-T	25.0	0.15	Pent. Amp. Tri.-Amp.	100 100	3.0 1.0	100	7.6 0.6	2.0	185,000 75,000	2,000 1,500	370 112.5	Pentode Section Triode Section		
6C6G	Tetrode	7-AC	25.0	0.30	Power Amp.	Characteristics Same as Type 6Y6G.										
6L6GT/G	Tetrode	7-AC	25.0	0.30	Power Amp.	110 200	7.5 8.0	110 110	49.0 50.0	4.0 2.0	13,000 30,000	9,000 9,500	..... .....	2,000 3,000	2,100 4,300	
6Y5	Duodiode	6-E	25.0	0.30	H-W Rect.	235 A-C Volts per Plate, RMS, 75 Ma. Output Current per Plate.										
6Z5	Duodiode	6-E	25.0	0.30	Doubler	Characteristics Same as Type 25Z6GT/G.										
6Z6GT/G	Duodiode	7-Q	25.0	0.30	Doubler H-W Rect.	117 A-C Volts per Plate, RMS, 75 Ma. Output Current per Plate. 235 A-C Volts, RMS, 75 Ma. Output Current per Plate.										
6	Triode	4-D	1.5	1.05	Amplifier	90 135 180	7.0 10.0 14.5	..... ..... .....	2.9 5.5 6.2	..... ..... .....	8,900 7,600 7,300	935 1,100 1,150	8.3 8.3 8.3	..... ..... .....	..... ..... .....	
7, 27S	Triode	5-A	2.5	1.75	Amplifier	90 135 180 250	6.0 9.0 13.5 21.0	..... ..... ..... .....	3.0 4.7 5.0 5.2	..... ..... ..... .....	10,000 9,000 9,000 9,250	900 1,000 1,000 975	9.0 9.0 9.0 9.0	..... ..... ..... .....	..... ..... ..... .....	
					Detector	250	30.0†	(Plate Current to be adjusted to 0.2 Ma. with no Input Signal)								

applied through 250,000 ohms.
per Tube or Section—No Signal.
Plate and Target Supply Voltage.

**Triode Operation.

††Applied through 200,000 ohms.

‡‡With Average Power Input of 320 Mw. Grid to Grid.

‡Pentode Operation.

††For two tubes with 40 volts RMS applied to each grid.

¶Plate to Plate.

‡Applied through 20,000 ohms.

‡Approximate.

‡Conversion Conductance

150 Volts RMS applied to two grids.

Type	Class	Base	Filament Rating		Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma.	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts
0	Triode	4-D	2.0	0.06	Det.-Amp.	90 135 180	4.5 9.0 13.5	.....	2.5 3.0 3.1	.....	11,000 10,300 10,300	850 900 900	9.3 9.3 9.3	.....	.....
1	Triode	4-D	2.0	0.13	Power Amp.	135 180	22.5 30.0	.....	8.0 12.3	.....	4,100 3,600	925 1,050	3.8 3.8	7,000 5,700	185 375
2	Tetrode	4-K	2.0	0.06	R-F Amp. Detector	135 180 180	3.0 3.0 6.0†	67.5 67.5 67.5	1.7 1.7 (Plate Current to be adjusted to 0.2 Ma. with no input signal)	0.4 0.4	950,000 1.2 Meg. 650	640 650 780	610 780	.....	.....
2L7GT	Diode, Tet.	8-Z	32.5	0.30	Rectifier Power Amp.	125 RMS 110	7.5	.....	60 40	.....	.....	.....	.....	2,600	1,000
3	Pentode	5-K	2.0	0.26	Power Amp.	135 180	13.5 18.0	135 180	14.5 22.0	3.0 5.0	50,000 55,000	1,450 1,700	70 90	7,000 6,000	700 1,400
4	Pentode	4-M	2.0	0.06	R-F Amp.	67.5 135 180	3.0 3.0 3.0	67.5 67.5 67.5	2.7 2.8 2.8	1.1 1.0 1.0	400,000 600,000 1 Meg.	560 600 620	224 360 620	.....	.....
5/51, 355/51S	Tetrode	5-E	2.5	1.75	R-F Amp. A-F Amp.	180 250 250*	3.0 3.0 1.0	90.0 90.0 45 to 67.5	6.3 6.5 0.5	2.5 2.5	300,000 400,000 2 Meg.	1,020 1,050	305 420	.....	.....
5A5	Tetrode	6-AA	35.0	0.15	Power Amp.	110 200	7.5 8.0	110 110	40.0 41.0	3.0 2.0	14,000† 40,000†	5,800 5,900	.....	2,500 4,500	1,500 3,300
5L6GT/G	Tetrode	7-AC	35.0	0.15	Power Amp.	110 200	7.5 8.0	110 110	40.0 41.0	3.0 2.0	14,000† 40,000†	5,800 5,900	.....	2,500 4,500	1,500 3,300
5Y4	Diode	5-AL	35.0	0.15	H-W Rect.	235 Max. A-C Volts, RMS, 60 Ma. Output Current with Panel Lamp. 235 Max. A-C Volts, RMS, 100 Ma. Output Current without Panel Lamp.									
5Z3	Diode	4-Z	35.0	0.15	H-W Rect.	235 Max. A-C Volts per Plate, RMS, 100 Ma. Output Current, Condenser Input to Filter.									
5Z4GT	Diode	5-AA	35.0	0.15	H-W Rect.	117 A-C Volts, RMS, 100 Ma. Output Current. Condenser Input to Filter.									
5Z5GT/G	Diode	6-AD	35.0	0.15	H-W Rect.	Characteristics Same as Type 40Z5/45Z5GT.									
6	Tetrode	5-E	6.3	0.30	R-F Amp. Detector	135 180 250 250	1.5 3.0 3.0 6.0†	67.5 90.0 90.0 20 to 25 (Plate Current to be adjusted to 0.1 Ma. with no input signal)	2.8 3.1 3.2	Not Over 1/4 of Plate Ma.	575,000 500,000 550,000	1,000 1,050 1,080	475 525 595	.....	.....
7	Triode	5-A	6.3	0.30	Amplifier	135 180 250	9.0 13.5 18.0	.....	4.1 4.3 7.5	.....	10,000 10,200 8,400	925 900 1,100	9.2 9.2 9.2	.....	.....
8	Pentode	5-F	6.3	0.30	Power Amp.	135 180 250	13.5 18.0 25.0	135 180 250	9.0 14.0 22.0	1.5 2.4 3.8	130,000 110,000 100,000	925 1,050 1,200	120 120 120	13,500 11,600 10,000	550 1,000 2,500
9/44	Pentode	5-F	6.3	0.30	R-F Amp. A-F Amp.	90 180 250 250*	3.0 3.0 3.0 1.0	90.0 90.0 90.0 67.5	5.6 5.8 5.8 0.5	1.6 1.4 1.4	375,000 750,000 1 Meg. 2 Meg.	960 1,000 1,050	360 750 1,050	.....	.....
40Z5/ 45Z5GT	Diode	6-AD	45.0	0.15	H-W Rect.	117 A-C Volts, RMS, 100 Ma. Output Current without Panel Lamp Connected, or 60 Ma. with Panel Lamp.									
41	Pentode	6-B	6.3	0.40	Power Amp.	Characteristics Same as Type 6K6G.									
42	Pentode	6-B	6.3	0.65	Power Amp.	Characteristics Same as Type 6F6G.									
43	Pentode	6-B	25.0	0.30	Power Amp.	Characteristics Same as Type 25A6GT/G.									
45	Triode	4-D	2.5	1.50	Power Amp.	180 250 275	31.5 50.0 56.0	.....	31.0 34.0 36.0	.....	1,650 1,610 1,700	2,125 2,175 2,050	3.5 3.5 3.5	2,700 3,900 4,600	830 1,600 2,000
46	Tetrode	5-C	2.5	1.75	Power Amp.	250 300 400	33.0 0.0 0.0	Tie Gs to P Tie Gs to G Tie Gs to G	22.0 4.0† 6.0†	.....	2,380 (Class B Operation) (Class B Operation)	2,350	5.6	6,400 5,200† 5,800†	1,250 16,000 20,000
47	Pentode	5-B	2.5	1.75	Power Amp.	250	16.5	250	31.0	6.0	60,000	2,500	150	7,000	2,700
48	Tetrode	6-A	30.0	0.40	Power Amp.	95 125	20.0 22.5	95.0 100	52.0 52.0	12.0 12.0	4,000 11,000	3,900 3,900	15.6 43	1,500 1,500	2,000 3,000
49	Tetrode	5-C	2.0	0.12	Power Amp.	135 180	20.0 0.0	Tie Gs to P Tie Gs to G	6.0 2.0†	.....	4,175 (Two Tubes Class B Operation)	1,125	4.7	11,000 12,000†	170 3,500
50	Triode	4-D	7.5	1.25	Power Amp.	300 350 400 450	54.0 63.0 70.0 84.0	.....	35.0 45.0 55.0 55.0	.....	2,000 1,900 1,800 1,800	1,900 2,000 2,100 2,100	3.8 3.8 3.8 3.8	4,600 4,100 3,670 4,350	1,600 2,400 3,400 4,600
50A5	Tetrode	6-AA	50.0	0.15	Power Amp.	110 200	7.5 8.0	110 110	49.0 50.0	4.0 1.5	10,000† 35,000†	8,200 8,250	.....	2,000 3,000	2,100 4,300
50C6G	Tetrode	7-AC	50.0	0.15	Power Amp.	Characteristics Same as Type 25C6G.									
50L6GT	Tetrode	7-AC	50.0	0.15	Power Amp.	Characteristics Same as Type 25L6GT.									
50Y6GT/G	Duodiode	7-Q	50.0	0.15	F-W Rect.	Characteristics Same as Type 25Z6GT/G.									
50Z7G	Duodiode	8-AN	50.0	0.15	Doubler H-W Rect.	117 A-C Volts per Plate, RMS, 65 Ma. Output Current per Plate. With Current passing thru Panel Lamp Section. 235 A-C Volts, RMS, 65 Ma. Output Current.									
53	Duotriode	7-B	2.5	2.00	Power Amp.	Characteristics Same as Type 6A6.									
55, 55S	Duodiode Tri.	6-G	2.5	1.00	Det.-Amp.	Characteristics Same as Type 6V7G.									
56, 56S	Triode	5-A	2.5	1.00	Amplifier Detector	250 250	13.5 20.0†	.....	5.0 (Plate Current to be adjusted to 0.2 Ma. with no input signal)	.....	9,500	1,450	13.8	.....	.....
56AS	Triode	5-A	6.3	0.40	Amplifier	Characteristics Same as Type 56.									
57, 57S	Pentode	6-F	2.5	1.00	Amplifier Detector	100 250 250*	3.0 3.0 4.3†	100 100 100	2.0 2.0	0.5 0.5 (Plate Current to be adjusted to 0.1 Ma. with no input signal)	1 Meg. 1 Meg.†	1,185 1,225	.....	.....	.....
57AS	Pentode	6-F	6.3	0.40	Amplifier	Characteristics Same as Type 57.									
58, 58S	Pentode	6-F	2.5	1.00	Amplifier	100 250	3.0 3.0	100 100	8.0 8.2	2.2 2.0	250,000 800,000	1,500 1,600	.....	.....	.....
58AS	Pentode	6-F	6.3	0.40	Amplifier	Characteristics Same as Type 58.									
59	Pentode	7-A	2.5	2.00	Power Amp.	250** 250† 300 400	28.0 18.0 0.0 0.0	Tie Gs to P 250 Tie Gs to G and Su to P	26.0 35.0 20.0 26.0	.....	2,300 40,000 (Class B Operation Two Tubes) (Class B Operation Two Tubes)	2,600 2,500	6.0 100	5,000 6,000 4,600† 15,000†	1,250 3,000 20,000†
70L7GT	Diode-Tetrode	8-AA	70.0	0.15	Rectifier Amplifier	117 A-C Volts, RMS, 70 Ma. Output Current. Condenser Input to Filter. 110 110	7.5 7.5	110 40	.....	3.0	15,000	7,500	.....	2,000	1,800
71A	Triode	4-D	5.0	0.25	Power Amp.	90 135 180	16.5 27.0 40.5	.....	10.0 17.3 20.0	.....	2,170 1,820 1,750	1,400 1,650 1,700	3.0 3.0 3.0	3,000 3,000 4,800	125 400 790

Applied through 250,000 ohms.
†Per Tube or Section—No Signal.
‡Plate and Target Supply Voltage.

**Triode Operation.

††Applied through 200,000 ohms.

‡‡With Average Power Input of 2 Mw. Grid to Grid.

†Pentode Operation.

††For two tubes with 40 volts RMS applied to each grid.

‡Plate to Plate.

‡‡Applied through 20,000 ohms.

†Approximate.

‡Conversion Conductance
150 Volts RMS applied to two grids

Type	Class	Base	Filament Rating		Use	Plate Volts	Negative Grid Volts	Screen Volts	Plate Current Ma.	Screen Current Ma.	Plate Resistance Ohms	Micromhos Mutual Conductance	Amplification Factor	Ohms Load for Stated Power Output	Undistorted Power Output Milliwatts		
			Volts	Amps.													
75, 75S	Duodiode Tri.	6-G	6.3	0.30	Det.-Amp.	250	2.0	.....	0.9	.....	91,000	1,100	100	.....	.....		
76	Triode	5-A	6.3	0.30	Amplifier Detector	250	13.5	.....	5.0	.....	9,500	1,450	13.8	.....	.....		
						250	20.0†	.....	(Plate Current to be adjusted to 0.2 Ma. with no Input Signal)								
77	Pentode	6-F	6.3	0.30	Amplifier	100	1.5	60.0	1.7	0.4	600,000†	1,100	.....	.....	.....		
						250	3.0	100	2.3	0.5	1.0 Meg. +	1,250	.....	.....	.....		
78	Pentode	6-F	6.3	0.30	Amplifier	90	3.0	90.0	5.4	1.3	300,000†	1,275	.....	.....	.....		
						180	3.0	75.0	4.0	1.0	1 Meg. †	1,100	.....	.....	.....		
						250	3.0	100	7.0	1.7	800,000†	1,450	.....	.....	.....		
79	Duotriode	6-H	6.3	0.60	Power Amp.	180	0.0	.....	7.5‡	.....	(Class B Operation)	.....	.....	7,000‡	5,500		
						250	0.0	.....	10.5‡	.....	(Class B Operation)	.....	.....	14,000‡	8,000		
80	Duodiode	4-C	5.0	2.00	F-W Rect.	350 A-C Volts per Plate, RMS, 125 Ma. Output Current. Condenser Input to Filter.											
						500 A-C Volts per Plate, RMS, 125 Ma. Output Current. Choke Input to Filter.											
81	Diode	4-B	7.5	1.25	H-W Rect.	700 A-C Volts per Plate, RMS, 85 Ma. Output Current. Condenser Input to Filter.											
82	Duodiode	4-C	2.5	3.00	F-W Rect.	450 A-C Volts per Plate, RMS, 115 Ma. Output Current. Condenser Input to Filter.											
83	Duodiode	4-C	5.0	3.00	F-W Rect.	450 A-C Volts per Plate, RMS, 225 Ma. Output Current. Condenser Input to Filter.											
83V	Duodiode	4-AD	5.0	2.00	F-W Rect.	375 A-C Volts per Plate, RMS, 175 Ma. Output Current. Condenser Input to Filter.											
84/6Z4	Duodiode	5-D	6.3	0.50	F-W Rect.	325 A-C Volts per Plate, RMS, 60 Ma. Output Current. Condenser Input to Filter.											
85	Duodiode Tri.	6-G	6.3	0.30	Det.-Amp.	Characteristics Same as Type 6V7G.											
85AS	Duodiode Tri.	6-G	6.3	0.30	Det.-Amp.	250	9.0	.....	4.5	.....	16,000	1,250	20	.....	.....		
89	Pentode	6-F	6.3	0.40	Power Amp.	160**	20.0	.....	17.0	.....	3,300	1,425	4.7	7,000	300		
						180†	18.0	.....	20.0	.....	80,000	1,550	125	8,000	1,500		
						180	0.0		3.0‡		Class B Opern. Tie Su to P & Gs to G (Two Tubes)					9,400‡	3,500
VR90-30	Diode	4-W Voltage Regulator. With Starting Voltage at 125. Operating Volts 90. Operating Current 10 Ma. Min., 30 Ma. Max.															
V99	Triode	4-E	3.3	0.063	Det.-Amp.	90	4.5	.....	2.5	.....	15,500	425	6.6	.....	.....		
X99	Triode	4-D	3.3	0.063	Det.-Amp.	90	4.5	.....	2.5	.....	15,500	425	6.6	.....	.....		
VR105-30	Diode	4-W Voltage Regulator with Starting Voltage at 135. Operating Volts 105. Operating Current 5 Ma. Min., 30 Ma. Max.															
117L7/M7GT	Diode-Tet.	8-AO	117	0.09	H-W Rect. Power Amp.	117 A-C Volts, RMS, 75 Ma. Output Current. Condenser Input to Filter.											
						105	5.2	105	43	4.0	17,000†	5,300	.....	4,000	850		
117N7GT	Diode-Tet.	8-AV	117	0.09	H-W Rect. Power Amp.	117 A-C Volts, RMS, 75 Ma. Output Current. Condenser Input to Filter.											
						100	6.0	100	51	5.0	16,000†	7,000	.....	3,000	1,200		
117Z6GT/G	Duodiode	7-Q	117	0.075	Doubler	117 A-C Volts per Plate, RMS, 60 Ma. Output Current per Plate.											
VR150-30	Diode	4-W Voltage Regulator with Starting Voltage at 180. Operating Volts 150. Operating Current 5 Ma. Min., 40 Ma. Max.															
182B/482B	Triode	4-D	5.0	1.25	Power Amp.	250	35.0	.....	20.0	.....	2,500	2,000	5.0	4,500	1,350		
183/483	Triode	4-D	5.0	1.25	Power Amp.	250	65.0	.....	20.0	.....	2,000	1,500	3.0	4,500	1,800		
210-T	Triode	4-D	7.5	1.25	Power Amp.	(Standard Type 10 with Ceramic Base, See Type 10 Characteristics)											
485	Triode	5-A	3.0	1.25	Det.-Amp.	180	9.0	.....	5.8	.....	8,900	1,400	12.5	.....	.....		
864	Triode	4-D	1.1	0.25	Det.-Amp.	90	4.5	.....	2.9	.....	13,500	610	8.2	.....	.....		
						135	9.0	.....	3.5	.....	12,700	645	8.2	.....	.....		
950	Pentode	5-K	2.0	0.12	Power Amp.	135	16.5	135	7.0	2.0	125,000	1,000	125	13,500	575		
1221	Pentode	6-F	6.3	0.30	Amplifier	Special Non-Microphonic Tube, Characteristics Same as Type 6C6.											
1223	Pentode	7-R	6.3	0.30	Amplifier	"G" Equivalent of Type 1221 Above.											
1231	Pentode	8-V	6.3	0.45	Pen.-Amp. Tet.-Amp.	300	.....	150	10.0	2.5	700,000	5,500	3,850 Bias Res. = 200 Ohms.				
						300	.....	150	12.0	0.5	540,000	6,500	3,500 Bias Res. = 200 Ohms.				
1612	Heptode	7-T	6.3	0.30	Mixer Amplifier	250	6.0	150	3.3	9.2	1 Meg. +	350A	(G3 = Neg. 15 V.)				
						250	3.0	100	5.3	6.5	600,000	1,100	(G3 = Neg. 3.0 V.)				
XXD	Duotriode	8-AC	12.6	0.15	Amplifier	250	10.0	.....	9.0	.....	7,600	2,100	16	(One Section)			
XXL	Triode	5-AC	6.3	0.30	Amplifier	100	0.0	.....	10.0	.....	7,000	3,600	25	.....	.....		
						250	8.0	.....	8.0	.....	8,700	2,300	20	.....	.....		

*Applied through 250,000 ohms.
†Per Tube or Section—No Signal.
‡Plate and Target Supply Voltage.

**Triode Operation.
††Applied through 200,000 ohms.
‡‡With Average Power Input of 320 Mw. Grid to Grid.

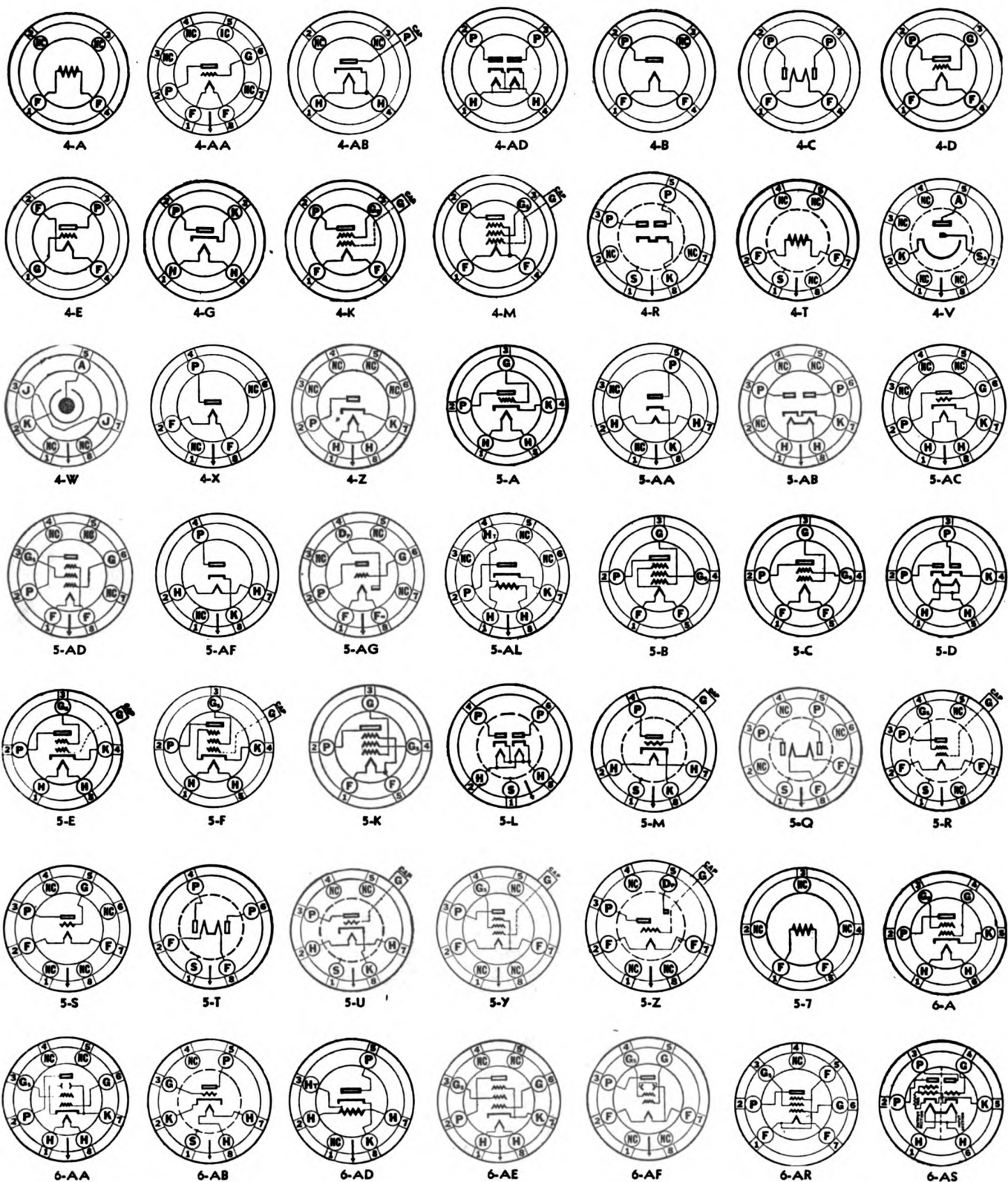
‡Pentode Operation.
††For two tubes with 40 volts RMS applied to each grid.
□ Applied through 20,000 ohms.

†Plate to Plate.
‡Approximate.
‡‡Conversion Conductance
150 Volts RMS applied to two grids.

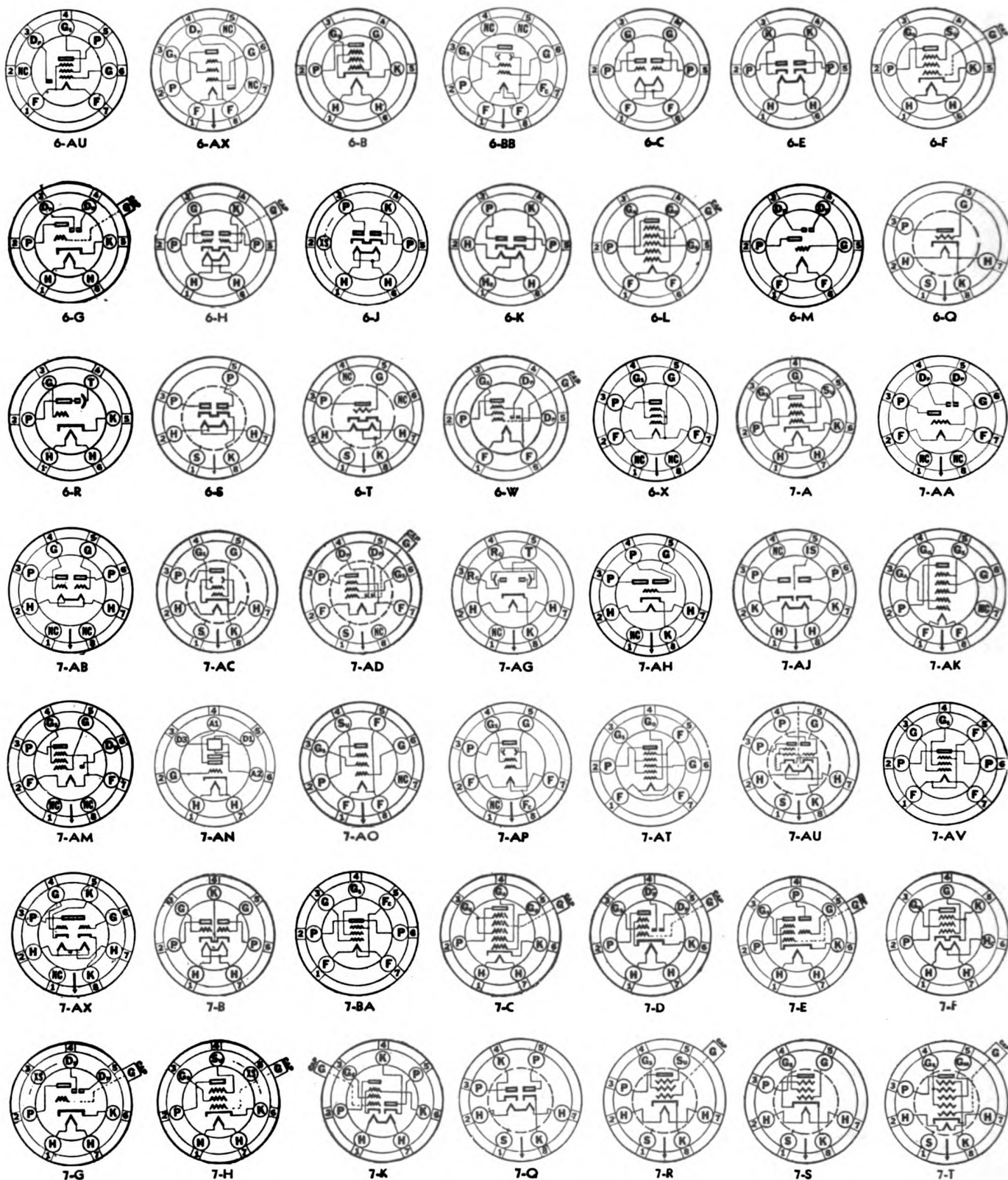
SYLVANIA PANEL LAMP CHARACTERISTICS

Type No.	Cir-cuit Volts	Design		Bead Color	Bulb Style	Miniature Base	Usual Service	Type No.		Type No.	Cir-cuit Volts	Design		Bead Color	Bulb Style	Miniature Base	Usual Service	Type No.
		Volts	Amp.									Volts	Amp.					
S40	6-8	6.3	0.15	Brown	T-3¼	Screw	Radio Dials	S40		*S49	2.0	2.0	0.06	Pink	T-3¼	Bayonet	Battery Set Dials	*S49
S41	2.5	2.5	0.50	White	T-3¼	Screw	Radio Dials	S41		S50	6-8	7.5	0.20	White	G-3½	Screw	Auto Sets, Flash Lights	S50
S42	3.2	3.2	0.35	Green	T-3¼	Screw	Radio Dials	S42		S51	6-8	7.5	0.20	White	G-3½	Bayonet	Auto Sets Auto Panels	S51
S43	2.5	2.5	0.50	White	T-3¼	Bayonet	Radio Dials and Tuning Meters	S43		S55	6-8	6.5	0.40	White	G-4½	Bayonet	Auto Sets, Parking Lights	S55
S44	6-8	6.3	0.25	Blue	T-3¼	Bayonet	Radio Dials and Tuning Meters	S44		S292	2.9	2.9	0.17	White	T-3¼	Screw	Radio Dials	S292
S45	3.2	3.2	0.35	White	T-3¼	Bayonet	Radio Dials	S45		S292A	2.9	2.9	0.17	White	T-3¼	Bayonet	Radio Dials Coin Machines	S292A
S46	6-8	6.3	0.25	Blue	T-3¼	Screw	Radio Dials and Tuning Meters	S46		S1455	18.0	18.0	0.25	Brown	G-5	Screw	Coin Machines	S1455
*S47	6-9	6.3	0.15	Brown	T-3¼	Bayonet	Radio Dials	*S47		S1455A	18.0	18.0	0.25	Brown	G-5	Bayonet	Coin Machines	S1455A
S48	2.0	2.0	0.06	Pink	T-3¼	Screw	Battery Set Dials	S48										

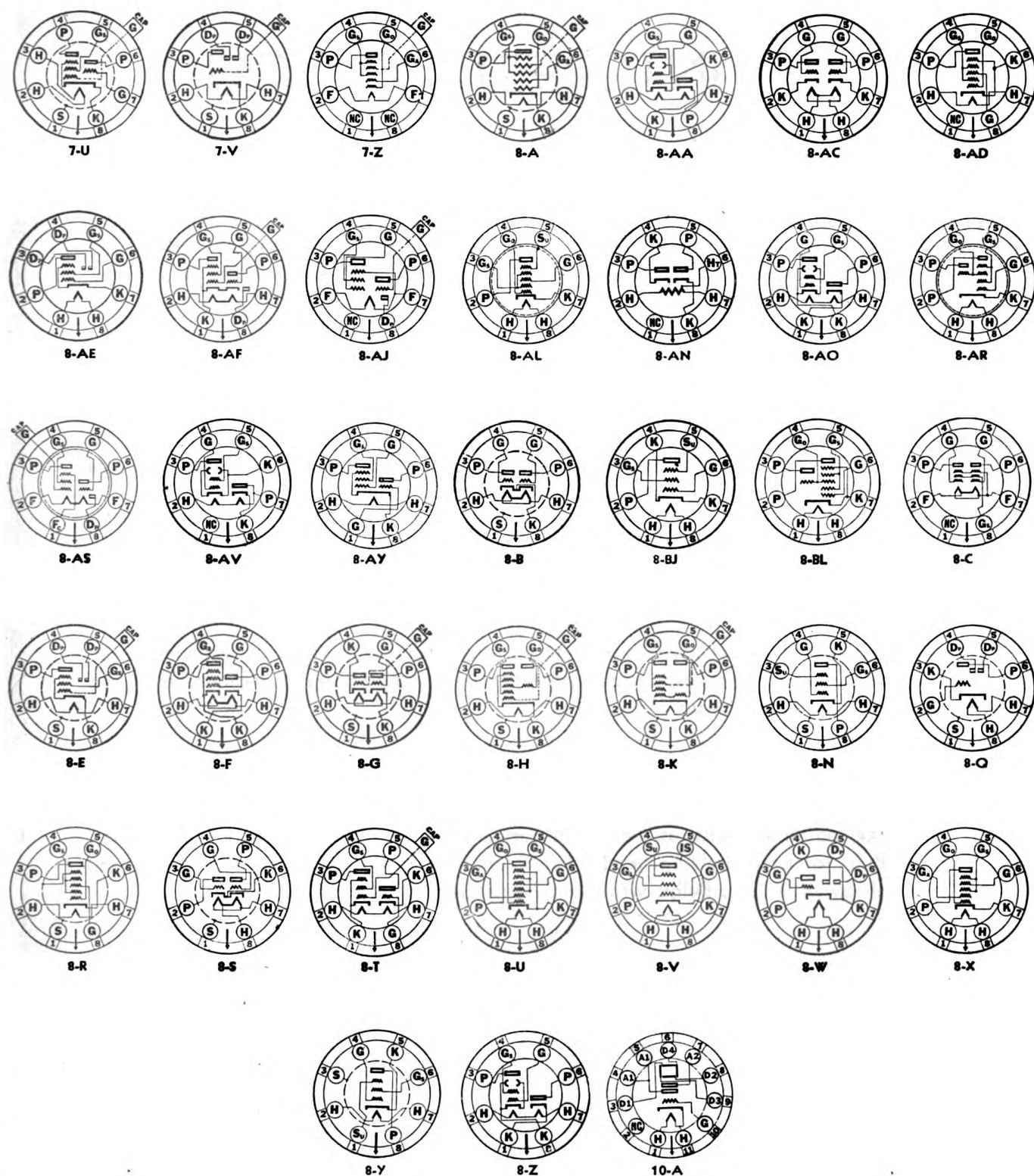
*Sylvania Types S47 and S49 are interchangeable with Types 40A and 49A, respectively, in other brands.



SYMBOLS: A—Anode, A1—Anode 1, A2—Anode 2, D1—Deflector 1, D2—Deflector 2, D3—Deflector 3, D4—Deflector 4, Dp—Diode Plate, F—Filament, Fc—Filament Center, G—Control Grid, GA—Anode Grid, GM—Modulator Grid, Go—Oscillator Grid, Gs—Screen Grid, H—Heater, Hc—Heater Center, Ht—Heater Tap, IC—Internal Connection, IS—Internal Shield, J—Jumper, K—Cathode, NC—No Connection, P—Plate, Rc—Ray Control, S—Metal Shell, SA—Starter Anode, Su—Suppressor Grid, T—Target, XS—External Shield, □—Top Cap, —>—Locating Pin.



SYMBOLS: A—Anode, A1—Anode 1, A2—Anode 2, D1—Deflector 1, D2—Deflector 2, D3—Deflector 3, D4—Deflector 4, Dp—Diode Plate, F—Filament, Fc—Filament Center, G—Control Grid, GA—Anode Grid, GM—Modulator Grid, Go—Oscillator Grid, Gs—Screen Grid, H—Heater, Hc—Heater Center, Ht—Heater Tap, IC—Internal Connection, IS—Internal Shield, J—Jumper, K—Cathode, NC—No Connection, P—Plate, Rc—Ray Control, S—Metal Shell, SA—Starter Anode, Su—Suppressor Grid, T—Target, XS—External Shield, □—Top Cap, —>—Locating Pin.



SYMBOLS: A—Anode, A1—Anode 1, A2—Anode 2, D1—Deflector 1, D2—Deflector 2, D3—Deflector 3, D4—Deflector 4, Dp—Diode Plate, F—Filament, Fc—Filament Center, G—Control Grid, G_A—Anode Grid, G_M—Modulator Grid, G_O—Oscillator Grid, G_S—Screen Grid, H—Heater, Hc—Heater Center, Ht—Heater Tap, IC—Internal Connection, IS—Internal Shield, J—Jumper, K—Cathode, NC—No Connection, P—Plate, Rc—Ray Control, S—Metal Shell, SA—Starter Anode, Su—Suppressor Grid, T—Target, XS—External Shield, □—Top Cap, —>—Locating Pin.

OF INTEREST TO YOU

Besides this characteristic sheet, Sylvania has a generous assortment of Sales and Service Helps, most of which are free upon request. Semi-technical literature for the service man such as Tube and Base Diagram Charts, the Service Hints Booklet, the Tube Complement Book (35c) and the Technical Manual (35c), are in constant demand. Window Displays, streamers and transparencies, price literature, circulars, book matches, electric signs, mailing cards, news mats, and plain or imprinted tube stickers are provided generously as an assistance to dealers and service men.

Sylvania News, a regular monthly publication featuring a separate Technical Section, items of trade interest, personal interviews, and service helps, is available to everyone. Inquiries about Sylvania News and any other sales or service helps, as well as Sylvania Radio Tubes, should be addressed to Sylvania Electric Products Inc., Emporium, Pa.

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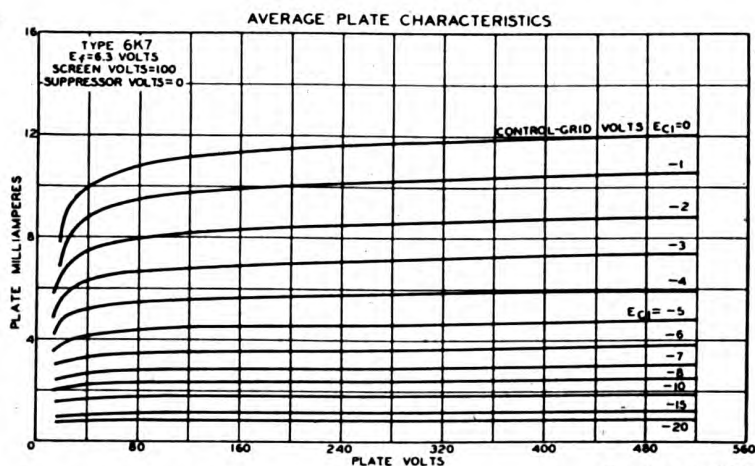
SYLVANIA
ELECTRIC PRODUCTS INC.
FORMERLY
HYGRADE SYLVANIA CORPORATION

EMPORIUM, PENNA.

PLANTS IN PENNSYLVANIA AND MASSACHUSETTS

required to produce the same small change in plate current. Triodes have amplification factors from 3 to 20. A few of the high-mu triodes have amplification up to 100. An average tetrode may have an amplification of 300, while a pentode may have a mu over 1,000.

PENTODE PLATE CHARACTERISTIC CURVES. As you can observe from the plate characteristic curves of a type 6K7 tube (a commonly used pentode), the plate current does not change much with plate voltage variations. This is because the screen grid is positive at a fixed potential at all times. Since a very large plate voltage change is needed in a pentode to produce the same change in I_p as a small grid voltage, the ratio of "change in E_p " to "change in E_g " is large, making mu also very large.



Courtesy of RCA

Figure 123. Because the plate voltage of a pentode has little effect on the plate current, the average plate characteristics of a pentode have a different appearance than the family of curves for a triode. Since the grid voltage has so much more effect than the plate voltage, the amplification factor is very high.

PLATE RESISTANCE. Even with zero grid voltage in our experimental circuit, plate current was present with a definite plate voltage. The tube must have presented some impedance to limit the current. We are interested in the opposition to A.C. current which results if the voltages are varied. We use the symbol r_p for plate resistance described, and write instead of "a small change," the letter d, in front of the symbol, like this:

$$r_p = \frac{dE_p}{dI_p} \quad \text{when } E_g \text{ is constant}$$

This value may be obtained from the plate characteristic charts in a manner similar to that we have used to calculate the value of mu.

TRANSCONDUCTANCE. This is an important factor which tells us much about the vacuum tube. As you can see from the formula below, it is equal to a small change in plate current divided by a small change in grid voltage which causes it, while the plate voltage is fixed. The symbol for transconductance is G_m .

$$G_m = \frac{dI_p}{dE_g} \quad E_p \text{ constant}$$

PENTODE PLATE CURVES

This is the continuation from page 96.

By ratio, we mean the division of one quantity by the other.

Notice that the characteristic curves are not spaced apart equal amounts for equal grid voltages. This property of certain radio frequency pentodes is obtained by placing the grid wires in a special shape. Remote cut off characteristics (small plate current change for large negative grid voltages) permits a tube such as 6K7 to be used in manual volume control circuits, while regular pentodes would cause distortion when operated in radio circuits handling strong signals from local broadcasting stations.

Plate resistance, r_p , is a dynamic quality and is useful in considering the operation of a tube in a circuit. The value of plate resistance is obtained from the formula stated and it *cannot* be obtained by simply dividing the plate supply voltage by the average plate current.

CHARACTERISTIC CHARTS

The same procedure is followed in finding information about any other tube. The type 6K7 tube is listed on page 100.

Base connections are shown on pages 105 to 107, inclusive. Since most circuits show tube base connections as viewed from the bottom, the base connections in the charts also show bottom views.

Filament rating information is very important. Tubes will operate correctly only with the proper voltage. In case the tubes are connected in series (that is, the filaments are connected in series as in AC-DC sets), the current consumption must be considered.

This does not mean that only the plate voltages indicated may be used. Any voltages in-between (and perhaps even higher and lower voltages in some cases) may be employed, but the data are presented for typical plate supply voltages.

These values are based on several sample tubes that have been tested. If you check these figures with an actual circuit, you may find slight variations from the values given.

Transconductance can also be expressed in terms of the amplification factor and plate resistance, as below:

$$G_m = \frac{\mu}{r_p}$$

INFORMATION ON TUBES. The radio technician must have data on all radio tubes used in equipment. He needs this information for repair, proper operation, and design. The essential information about all receiving type vacuum tubes is presented on pages 97 to 108, inclusive. We will now tell you how to use these data.

Let us say that the information about a type 6K7 tube is needed. We notice that the types are listed in numerical order in the first column. We move along until we find 6K7. In line with this number, in the different columns, we will find the information we need. As you will see from the head of the second column, the information there tells us to what "Class" this tube belongs. The 6K7 is a pentode.

The next column tells us that this tube has a 7-R base. All base connections are illustrated at end of the tables. If you will find base marked 7-R, it will tell you how to connect a 6K7. This information is very important. It permits you to find out how the elements of the tube are connected at the base—what terminal is the plate, what terminal is the cathode, etc.

Certain information about some tubes is of a special nature and is explained with the aid of foot-notes stated at the bottom of each page and referred to the proper place with a suitable mark.

The columns under "Filament Rating" tell us what voltage to use for the tube and what current will be taken. The 6K7 operates from 6.3 volts, and draws 0.3 amperes. You can find out if the tube is directly heated or if it has a cathode from the base connection diagram. And the next column tells you the usual function of the tube; *amplifier* for 6K7 tube.

The next column is headed, "Plate Volts." Under 6K7 and some of the other tubes, several different values of plate voltage are listed. This simply means that you select the balance of the information on the basis of the plate voltage your circuit is using. The values are not critical, you find out the plate voltage in the circuit under consideration and use the information for the closest plate voltage given in the charts. Let us say that the tube we are using is operated with 250 volts on the plate. Be careful to follow across the line where 250 appears, and under 6K7.

The next line tells us that under this condition, the "negative grid volts" should be 3. And the next line lets us know that the screen grid should have a voltage of 100. The next column covers "plate current ma." and we learn that the average plate current will be 7 milliamperes. Please notice that the plate current is not the same for the other operating conditions for this same 6K7 tube. And from the next column, we find out that the screen grid current is 1.7 ma. Please follow our findings carefully, checking every value we mentioned.

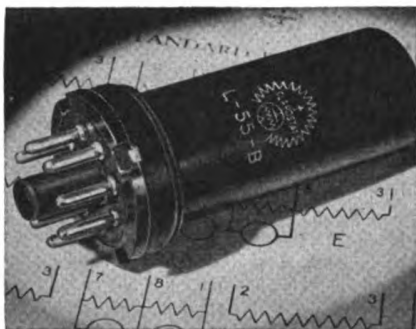
As is usual for pentodes, we find in the next column that the 6K7 pentode has a high plate resistance of 800,000 ohms. Please remember that plate resistance, r_p , as any resistance, is measured in ohms.

The value of transconductance is stated in the next column. Conductance is the reciprocal of resistance and is measured in *mhos*. Mho is o-h-m written backwards. One-millionth of a mho is a micro-mho. The type 6K7 tube has a transconductance of 1,450 micro-mhos under the conditions we are considering. The next column gives us the value of the amplification factor, 1,160 in this case. The last two columns present information of importance only in case of power output tubes. The 6K7 is not used for this purpose.

Please refer to the radio you studied and obtain the type numbers of the tubes employed. Find out as much as you can about these tubes by using the information given in the charts.

SIMILARITY OF TYPES. A great many tube types are similar in major aspects. Compare types 6D6 and 78. They are almost alike and, in fact, can be interchanged in all circuits. Now compare these two types with a type 58. Also exactly the same, but the filament voltages are different. How about our friend, 6K7? Almost the same, but the 6K7 is a metal tube and requires an octal socket while the others used a six prong socket. And the 6K7-G is the same as 6K7, but is the glass envelope equivalent. Check also 12K7 and 6SK7.

Also compare the similarity of these output tubes: 41, 42, 43, 6F6, and the pentode section of 25A7-G, 25A6. Are any of these directly interchangeable?



Courtesy Clarostat Mfg. Co.
Figure 124. Ballast tubes have the appearance of regular vacuum tubes, but are resistors made to resemble regular tubes.

FILAMENT CONNECTIONS. Usually any one radio uses radio tubes of the same filament voltage, and they are wired in parallel and obtain the operating voltage from a winding of the power transformer. For example, some sets use 6.3 volt tubes while other employ 2.5 volt tubes. To save on equipment, lower priced radio sets have the tubes wired in series. In such instances, the tubes used must be rated at the same filament current, but not necessarily at the same voltage. In one radio, types 6K7, 6A8, 6Q7, 25L6, and 25Z6, are used and are wired in series. Using the charts, please check to see if all of these tubes have the same filament current of 0.3 amperes, and if their voltages add up to about 69 volts. These tubes may be connected in series across 110 volts, provided the balance of $(110 - 69) = 41$ volts is dropped in a series resistor. This resistor may be separate, or may be incorporated in the line cord, or may take the form of a ballast tube. Although

SIMILAR TYPES OF TUBES

The amplification factor is not stated in the table since it varies a great deal with the circuit employed. The value of 1,160 stated may be used in estimating the gain from this tube.

The type 25A7-G is a 25 volt filament dual purpose tube serving the same purpose as both the 43 and the 12Z3 tubes.

As a radio technician, you must realize that ballast tubes are wire-wound resistors in function and are not vacuum tubes. In fact, you may feel safe in removing the metal cover section from a ballast tube, and you will see the resistance wire wound on a support inside.

The rectifier tube (usually type 80 in A.C. type radios) may be of other filament voltage. The rectifier tube requires a separate winding on the transformer anyway and this winding may be made for any voltage required.

In AC-DC radio receivers, the tubes are usually connected in series necessitating the use of tubes with the same filament current ratings.

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SPECIAL VACUUM TUBES

The tuning eye tube is controlled from the AVC voltage which in turn depends on the signal being received. If a local station is tuned in properly, it will develop maximum AVC voltage. This voltage, in turn, will make the shadow of the eye minimum.

A chart is supplied with the adapter showing the wire color code used and explaining in greater detail the connections to the radio.

A great deal more information on the function of photo-electric equipment will be presented in a complete lesson in Volume 3. This introduction is included to make the presentation on vacuum tubes complete.

ballast tubes have the appearance of regular tubes, but are nothing more than pig-in type resistors.

TUNING-EYE TUBES. The types 6E5, 6G5, and others finding indicator tubes are finding extensive use in modern sets for certain types of test equipment. These tubes may also be added to any radio having automatic volume control. In such cases, the tube filament is simply wired in series with other tubes in AC-DC type sets, or connected to the power transformer filament winding. Usually the transformer can easily handle an additional tube. In sets using 2.5 volt tubes, type 2E5 must be employed.



Courtesy American Phenolic Corp.

Figure 125. A tuning-eye tube can be added to any radio receiver having AVC. Adapter socket attachment is commercially available.

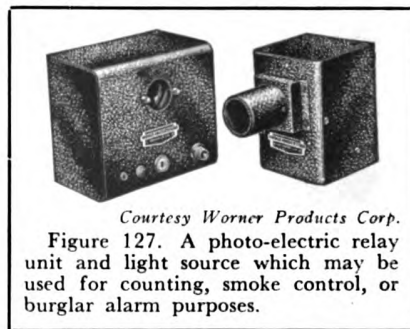
The adapter sockets supplied (as illustrated) have an internal plate resistor and are simply connected to the filament supply, high voltage point, chassis or negative return, and a point of the correct AVC voltage.

PHOTO-ELECTRIC CELLS. Surfaces treated with certain chemicals will emit electrons under the influence of light. This action is very similar to the emission of heated cathodes. If a positive plate is placed in the bulb, the electrons will be attracted to the plate.



Figure 126. This is an illustration of a photo-cell used in motion picture sound equipment. The large plate is the cathode, the center wire is the anode.

Courtesy Continental Electric Co.



Courtesy Warner Products Corp.

Figure 127. A photo-electric relay unit and light source which may be used for counting, smoke control, or burglar alarm purposes.

Since more electrons are emitted when the light shining on the photo-cell is bright, light can be used to control the number of electrons leaving the photo-sensitive cathode. The number of electrons, of course, forms the current which in turn is controlled by the light source.

The different colors of light represent various wavelengths and are measured in special units. Please notice that the response of a human eye is not the same to different colors. The type "A" photo-cell made by G-M Laboratories, has a more uniform response

than . . . and this cell is effected by ultra-violet, and infra-red light.

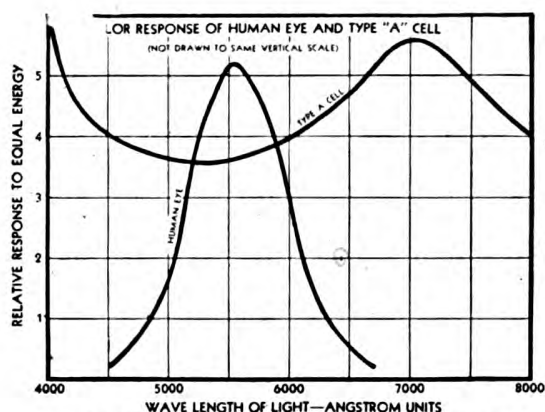


Figure 128. Comparison of the response of the human eye and of a photo-cell to light of different colors.

REVIEW QUESTIONS

Many applications of electronics depend on photo-electric cells and associated circuits.

REVIEW QUESTIONS AND PROBLEMS. 1. Increasing the temperature of the cathode will have what effect on the number of electrons emitted?

1. How high can the temperature be raised? What is the limiting factor?

2. Explain the action of a simple diode.

2. Does this action suggest any proof that electrons are negative?

3. How does the grid control the number of electrons reaching the plate?

3. Explain this action in your own words. Since the understanding of this operation is very important, we suggest that you write out this answer in your note-book.

4. Do you understand why the grid and plate of a triode form a condenser? What items make up the two condenser plates? What is the dielectric?

5. What is the usual potential on the screen grid? Is it ever made negative?

6. Name the five elements of a pentode. In what order are the grids placed, starting with the control grid?

7. Can you think of any advantages of multi-unit tubes?

8. Why is the control grid usually operated at a negative potential?

9. Referring to the characteristic curves of type 6C5, find the plate current with the plate voltage at 250, and the control grid voltage at minus 8 volts.

10. Explain how you can calculate the amplification factor by using information from characteristic curves.

10. How can the calculation of the amplification factor be carried out without the characteristic curves? What equipment will be needed?

11. Find the plate resistance of type 6C5 tube using the characteristic curves. Please notice that you will obtain the wrong answer by simply dividing plate voltage by plate current.

12. What are you told about the type 56 tube in the charts? Can you find the plate resistance and amplification factor of this tube?

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LESSON 10

Power Supplies

The electrical power needed for electronic equipment must be of sufficient capacity and of the proper type. Usually direct current is needed for the plate supply, while the filaments (in most cases) may be operated from A.C. of the correct voltage.

The hum is caused by the cathode heating up and cooling down many times per second as the A.C. filament supply periodically increased and decreased. By making the cathodes so that a great deal of the heat is retained and the temperature is kept constant while the A.C. filament voltage continuously passed through the maximum-minimum variations, this fault is eliminated.

This manner of producing required power is still used for portable equipment.

POWER NEEDED FOR RADIO EQUIPMENT. Almost every piece of radio equipment uses vacuum tubes. We have already learned that the filaments of these tubes require electrical energy to create the needed heat. Different tubes have filaments which operate at various voltages and require various amounts of power. If you will refer to the tube charts, you will note, for example, that a type 1N5-G battery tube requires a filament voltage of 1.4 volts, and a current of .05 amperes. Since power equals $E \times I$, this tube uses .07 watts for heating the filament. This is a very small amount of power and this tube may be used with a battery supply. Compare this tube with a 6K7 type. Here the filament voltage is 6.3 volts, the current is 0.3 amperes, or the power is 1.89 watts, an average figure.

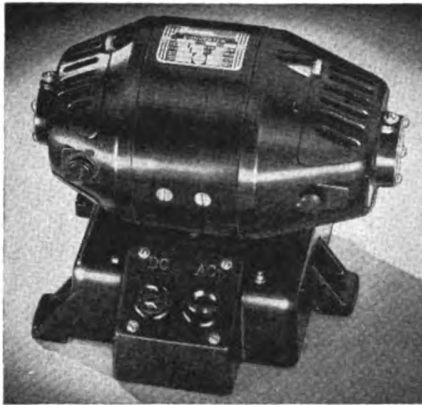
Usually plate voltages, anywhere from 90 to 300 volts, are needed in radio receivers, and these voltages may go up to several thousand volts in medium-size transmitters. These voltages must be supplied and must be D.C. to give proper operation. Power is also needed in some equipment for lighting pilot bulbs, energizing magnetic fields, or for operating relays.

HISTORICAL DEVELOPMENT. Much radio equipment, both receiving and transmitting, up to about 1925, depended upon batteries for power needed. For radio receivers, a single storage battery or several dry cells supplied the filament power. If the voltage was too high, it was dropped to the proper value with an adjustable rheostat. These batteries were called "A" batteries, and you may find this terminology used in many old radio books. The plate voltage was obtained from several "B" batteries connected in series. A single "B" battery consisted of 30 small dry cells connected in series to give 45 volts. Two such batteries in series would deliver 90 volts; and a total 135 and 180 volts were also used.

The indirectly heated cathode type tubes were especially developed so that the filaments could be heated from A.C. of a suitable voltage. The cathode construction or very rugged type filaments permitted this type of operation and eliminated *hum* which was always present in the output when earlier type tubes were employed in this fashion.

Transmitters use a great deal of plate power, so the batteries employed for this purpose had to be replaced very often. Sometimes a generator (dynamo) was used to produce D.C. voltage of the required value. This voltage was filtered in a manner to be described, and served just as well as batteries. The generator, in turn, was rotated with an electric motor operated from the available 110 volts A.C. A motor-generator set of this type permitted A.C. operation.

RECTIFICATION. As you can see, the need was for an A.C. unit which could provide the required D.C. plate power to replace the inconvenient and expensive "B" batteries. Such a unit, together with indirectly heated or A.C. type tubes, would make a radio receiver operate directly from the usual source of electric power—110 volts A.C. The diode type vacuum tube made this achievement possible.



Courtesy Eicor, Inc.

Figure 129. Rotating converters can be used to change direct current to alternating current of any required voltage. It is also possible to use converters to change A.C. to D.C.

Consider very carefully the simple power supply circuit illustrated. You see a transformer which has its primary connected to 110 volts A.C. This transformer has two separate secondaries. One, marked LV for low voltage, is connected to the filament of the rectifier type diode tube. Please follow these connections through. For the time being, do not consider the resistor marked "load." Now trace through the connections from the HV or high voltage secondary. You see that one connection goes to the plate of the tube, while the other is grounded and should become the negative return of the plate supply. This is a complete circuit of a half-wave rectifier.

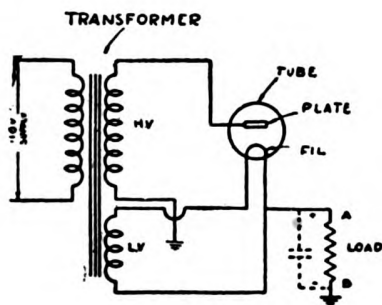


Figure 130. This is a basic circuit of a half-wave rectifier. It is important that you understand the function of this circuit since it is the basis for all usual power supplies.

If our transformer is connected to a 60 cycle power supply, we know that sixty times per second, one lead of the HV winding will be positive while the other lead will be negative, and sixty times per second, the polarity of these two leads will just reverse. Let us say that at one instant, the lower terminal of HV winding is negative. The electrons will be in excess at that point. They will pass through the chassis (ground), pass through the load, and come up to the filament. Now while the terminal we con-

A.C. RECTIFICATION

Electronic equipment, other than radio receiving sets, require similar type of power for proper operation.

This is a practical circuit and may be made to function in a power supply. In practice, the high voltage secondary may supply between 325 and 400 volts, while the LV secondary is designed to supply the required voltage for the filament of the rectifier tube employed.

Such power supply rectifier circuits are used with A.C. of any commercial power frequency.

VACUUM TUBE RECTIFIER

The curve of the output voltage may be obtained with the aid of an oscilloscope which uses a cathode ray tube and shows the wave shape of the voltage present in the circuit.

In the half-wave rectifier, current flows through the tube only half the time. This explains the name of the circuit.

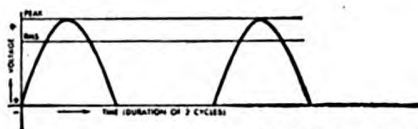
For most applications, the plate supply voltage must be pure D.C., similar to the current obtainable from batteries.

Several sections each consisting of a large capacity condenser and a large inductance (forming the filter) will succeed in keeping the output voltage at a constant value.

As you will probably notice, a full-wave rectifier actually consists of two ordinary half-wave rectifiers connected in a fashion so that one operates while the second is not conducting.

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sidered is negative, the upper terminal of HV is positive and is connected to the plate. The plate, therefore, will be positive also, and the electrons in the tube will be attracted across. The circuit will be completed, and current will pass through the load resistor.



Courtesy P. R. Mallory & Co.

Figure 131. This is an illustration of the voltage variations as delivered by a half-wave rectifier.

As the voltage of the half cycle was building up, the current in the load resistor was building up in very much the same fashion. See the illustration. Of course, if an A.C. voltmeter is connected across the transformer winding, it will read only the RMS value. If a D.C. voltmeter is connected across the load resistor, it will read a fixed voltage since the changes are happening too fast for the needle of the meter to follow.

When the top terminal of the HV winding becomes negative, as it will in the next half cycle, the plate will repel the electrons and no current will flow in the circuit. No current, please understand, will be flowing in the resistor and the voltage across the load resistor during this half cycle will be zero. And then the action will repeat itself.

We have already obtained from A.C., pulsating (varying) D.C., but we must have pure D.C. for proper operation of radio equipment. The current will be much smoother if we can incorporate a reservoir to absorb current when it is available in excess, and supply current when it is lacking. A condenser provides this reservoir action; it is connected across the load as indicated by the dotted lines. The condenser becomes charged when voltage is present across the load resistor, and then the condenser discharges when the voltage is missing. You probably recall that a condenser tends to keep the voltage constant which is just what we want. A condenser, of course, does not succeed in making the voltage absolutely constant, but, as you can see from the graph below, the voltage

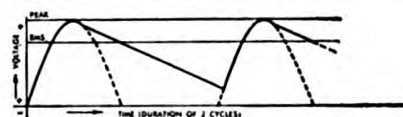


Figure 132. The action of a condenser in the power supply circuit tries to keep the voltage constant.

is more steady than it was before. The larger the capacity of the condenser, the smoother the output obtained.

FULL-WAVE RECTIFIER. In the half-wave rectifier we just studied, we noticed that rectification took place only during one half of each cycle, and the condenser was used to smooth out and fill in the gap as illustrated by the voltage graph. A full-wave rectifier uses a slightly different circuit with almost the same parts, but is much easier to filter, i.e. smooth-out.

Please study the circuit of the full-wave rectifier. Notice that the rectifier tube now has two separate plates, and the HV winding is center-tapped. Actually this winding produces as much

voltage between this tap and each end, as the previous transformer secondary did across the entire untapped HV winding.

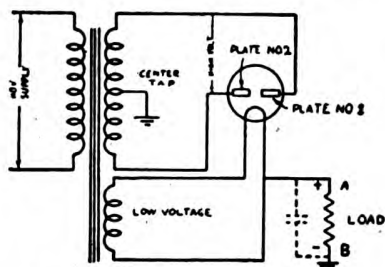


Figure 133. The full-wave power supply is used in almost all A.C. operated radio receivers.

In studying the circuit, assume that the center-tap is at zero potential. This means that while one terminal of the HV winding is positive, the other is negative. Only that plate connected to the terminal which is positive at the instant, will conduct electric current. At the same instant, the second plate will not conduct. In the next half cycle, the action of the two plates will reverse. Only one of the plates will conduct at a time. See the graph of the voltage across the load resistor.

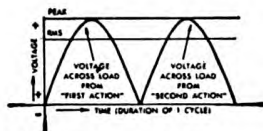


Figure 134. The voltage is delivered at all times and takes advantage of the two plates incorporated in the rectifier tube.

The condenser, as before, will smooth out the voltage variations. Follow the action through for several cycles, tracing the movement of electrons in parts of the circuit.

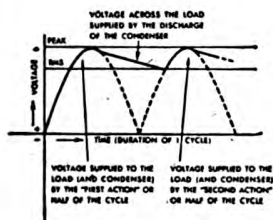


Figure 135. In a full-wave power supply, the filter condenser tends to even out the output voltage. The condenser action is similar to the action of a fly-wheel in an automobile.

Courtesy P. R. Mallory & Co.

FILTERING. In order to smooth out the voltage delivered by the rectifier, filters are used. Ordinarily, the filter consists of two or three condensers and one or two inductors known as chokes. Best filtering action is obtained when the chokes have low internal resistance, and the condensers are of large capacity. Most commercial power supplies are made up of two condensers across the D.C. voltage supply; one of these condensers is placed on each side of the choke. Since the first element, after the rectifier tube, is a condenser, this type of filter is known as *condenser-input*. If the first condenser is left out, and the first element after the rectifier is a choke, the filter is called *choke-input* type.

FILTER ACTION

Since the full-wave rectifier circuit requires the same number but somewhat more complex parts, its advantages over the half-wave rectifier circuit are always utilized in commercial A.C. operated electronic equipment.

Since every radio receiver for power line operation and almost every other electronic device uses a rectifier of this type, it is important that you understand the action explained. This information will be very useful when you will be called upon to service rectifier circuits.

In low priced radio receivers and in other equipment where the current is very low (a few milliamperes as in the cathode ray power supply), a resistor of about 3,000 ohms may be used instead of the filter choke. The filtering action is not as good with a resistor and the voltage drop across the resistor will be greater than the drop across a choke.

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PARTS OF A POWER SUPPLY

The audio hum caused by the presence of the ripple in the voltage of the power supply can be detected by carefully listening to the speaker of the set while the volume control is turned down. Only A.C. operated receivers, of course, will have the audible hum.



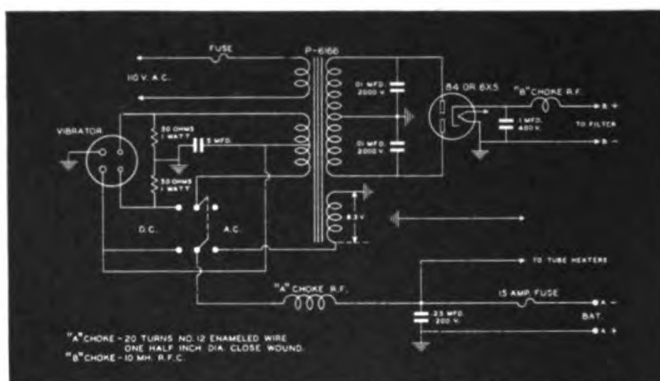
Courtesy Superior Electric Co.

A continuously adjustable voltage output power transformer may be used with power supplies to permit easy change and correction of the output voltage.

In commercial practice, electrolytic condensers are used. A radio receiver having a full-wave rectifier may employ two 8 mfd. condensers. A half-wave rectifier is always of the condenser-input type and has the first condenser of at least 20 mfd. (40 mfd. is common for AC-DC sets). The actual capacity is not critical and this is something to remember when servicing power supplies.

The filter eliminates the ripple or slight variation in the output voltage of the power supply. A well filtered commercial power supply has a very slight ripple present, but this is not noticeable in the operation of the radio. It is possible, by using several filter sections, to make the output as pure as that which is obtained from batteries, but such perfection is not needed for ordinary application.

COMPONENTS OF A POWER SUPPLY. What factors must be considered in selecting components for a new power supply or for replacement purposes? First, let us consider the power transformer.



Courtesy Standard Transformer Co.

Figure 136. This power supply circuit illustrates a unit which may be operated from 110 volts A.C. or from a 6 volt storage battery, to deliver plate voltage for a radio receiver or small transmitter.

This part is used in all full-wave rectifier type power supplies, but not in AC-DC half-wave rectifier type supplies. In the AC-DC sets, the 110 volt A.C. is applied to the plate of the rectifier, and the filament is wired in series with other tubes. But if the transformer is used, it must be selected on the basis of several factors. You must know from what voltage, of what frequency, the power supply will operate. Usually this source of power is 110 volts, 60 cycles. Next, you must know what filament voltages will be needed. The secondaries must supply the needed voltages and have sufficiently high rating to provide the needed current. If you have a winding on the transformer which supplies 5 volts, at 3 amperes, this can be used for a type 80 rectifier which needs 5 volts, at only 2 amperes. Check these figures against the tube characteristic chart data. Usually, at least one other secondary is included for the other tubes used, but a transformer may have several secondaries supplying filament power to different tubes. These low voltage secondaries may be center-tapped. Often this center-tap is grounded, but in modern sets one end of the filament winding may be grounded instead.

The high voltage secondary is almost always center-tapped. The voltage produced by one-half of the secondary should be about the same value as the D.C. voltage delivered to the choke. Actually this is not a fast rule, a radio may have a 700 volt secondary center-

tapped, deliver about 325 volts to the input of the filter, have a voltage drop of 75 volts in the choke (or speaker field which is often used as a choke), and deliver 250 volts to the radio set.

Most of the smaller rectifier type tubes, used in radio receivers and the power supplies of small transmitters, are listed in the tube characteristic charts under numbers in the eighties (80, 81, etc.) or under number 5, 6, 25, or 35, followed by letters X, Y, or Z, (5Y3, 25Z5). Look up a few of these tubes. Which of these will be best for small radio sets?



Courtesy Solar Mfg. Co.

Figure 137. In power supplies designed to deliver high voltages for radio transmitters, special high voltage condensers are used.

The condensers are selected with a voltage rating high enough for the power supply. The working voltage (WV) rating of the condenser indicates the maximum actual voltage of the power supply that may be used safely with this condenser. If a supply delivers 325 volts, pulsating D.C., and although the peaks may be much higher than this voltage, a condenser rated at 325 WV, or higher, may be used. If a condenser is rated at break down voltage only, make sure this voltage rating is at least 1.4 times greater than the D.C. voltage measured. In most full-wave power supplies, 450 WV condensers should be used; in AC-DC half-wave supplies, you are safe with condensers rated at 150 WV. The capacity will depend on the equipment the power supply is to serve, but the larger the capacity the better.

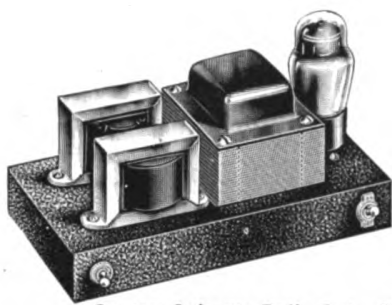
The chokes should have as high an inductance as is practical. You cannot depend on the ratings since the current at which the rating was made is usually omitted. In most cases, the larger chokes, big and husky, have greater inductance and are more expensive. The chokes are also rated in terms of maximum permissible current. The choke you use must be able to carry the maximum current supplied by the power supply. The D.C. resistance should be low or you will have very poor regulation. A well regulated power supply will give you about the same voltage output with considerable changes in current drain. In a poorly regulated supply, the voltage will change inversely with the current drain. This action leads to poor operation of the equipment. Placing a resistor across the output of the power supply, produces a steady drain from 10 to 20% of the total current and tends to stabilize the output.

The type of power supply circuits we have considered may be made to serve equipment requiring very high D.C. voltages. In such cases, the power transformer steps up the voltage to the required higher value. Tubes able to withstand the high voltages are used as rectifiers, and high voltage condensers (as illustrated) are employed in the filter. Special precautions are taken to insulate all other parts used. In such high voltage power supplies, safety circuits are incorporated to prevent damage to the equipment and to safeguard the operator if something electrically should go wrong.

When the current drain from a well filtered power supply is measured, approximately a constant amount is obtained. Although the current through the tubes of the equipment is changing up and down many times each second (with the presence of a signal), the average current, which is measured on the meter, remains the same. However, the power supply must deliver from instant to instant the exact current drawn by the equipment at the moment. This explains why good regulation is essential.

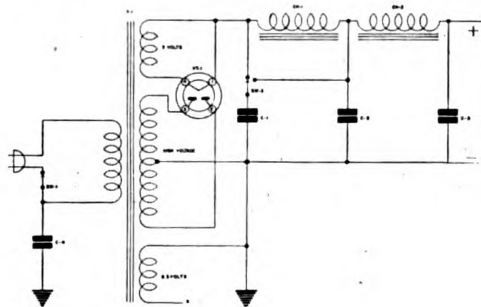
POWER FILTER CIRCUITS

The better type radios and sensitive electronic equipment may have choke-input filters, but the majority of radio receivers use condenser-input filter consisting of two condensers and a single choke.



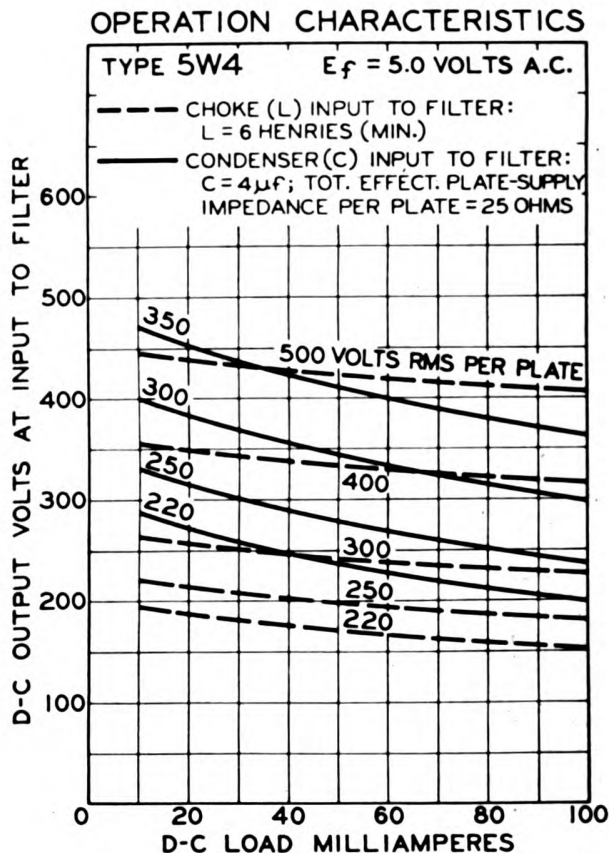
Courtesy Lafayette Radio Corp., Chicago

An illustration and schematic diagram of an experimental power supply. Switch SW-2 (single pole, double throw) is used to eliminate the input filter condenser and connect the first two filter condensers in parallel. The condenser, marked C-4 and connected from one side of the A.C. line to ground, is often included to prevent the line from picking up R.F. energy.



A bleeder (resistor which consumes current at all times) reduces the over all current variation and, thereby, tends to stabilize the voltage output.

COMPARISON OF CHOKE-INPUT AND CONDENSER-INPUT. When condenser-input filter is used, somewhat greater voltage is obtained with the same power supply than when choke-input is used. Please compare the various curves representing both types of input used with different voltage supplies. You will notice that at low current drain, higher voltage is delivered by the power supply with condenser-input, but the choke-input (dotted lines) give better regulation. By better regulation, we mean that as the current taken (as indicated on the base line) is increased, the output voltage remains almost the same. Variations in plate supply voltage will cause distortion and poor operation.



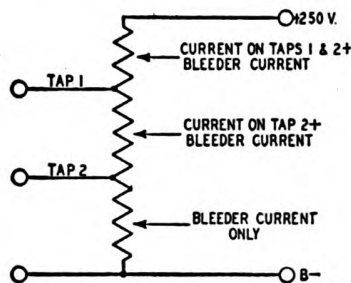
Courtesy RCA

Figure 138. These graphs illustrate the drop in output voltage of a power supply, as the current drain is increased.

VOLTAGE DIVIDER. A power supply is designed to deliver a given maximum voltage. Most radio receivers and transmitters require plate voltages of several different values to serve different tubes and a variety of circuits. It is possible to use a single resistor with sliding (adjustable) taps to serve as the bleeder and to permit an easy means for securing any required voltage between zero and the maximum voltage available.

Since the plate current consumption of an average radio is about 70 ma., a suitable bleeder should draw about 10 ma. Assuming that the supply gives about 250 volts, this will call for a 25,000 ohm bleeder. ($250/.010$, using Ohm's Law). The power dissipated by this resistor, just because of the bleeder current, will

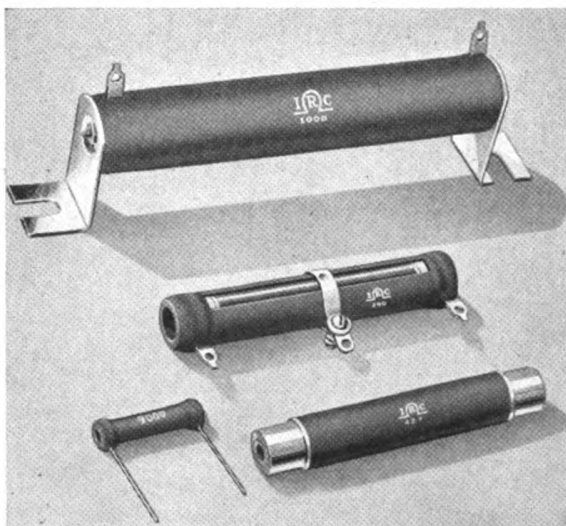
be, $250 \times .010$, or 25 watts. But, since we will also take current from the different taps, more power will be dissipated by the resistor and you should use at least a 50 watt size.



Courtesy P. R. Mallory & Co.

Figure 139. The voltage divider serves as a bleeder resistor and also gives voltages which are lower than the maximum available.

The two ends of the bleeder will be at the maximum and zero voltage respectively. Taps between these two extremes will provide any desired voltage between these limits. Now, besides the bleeder current, certain sections of the voltage divider will carry the current taken by some of the taps, the calculation of the exact setting of the taps is not too simple. You should guess the positions for the different taps, connect the equipment, and make final adjustment of the taps while taking measurements with a voltmeter.



Courtesy International Resistance Co.

Figure 140. Wire-wound resistors are supplied in various sizes and with different types of mounting brackets.

Care should be exercised in handling the power supply when the power is on. If possible, make all adjustments while the power is off. As an extra precaution, you should short circuit all filter condensers, using a piece of wire, before working on the unit.

VOLTAGE REGULATORS. Even the better designed power supplies do not have perfect voltage regulation. The output voltage changes with the line voltage variations, current drain, and age of the

PURPOSE OF VOLTAGE DIVIDER

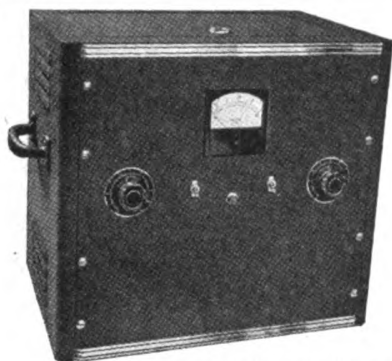
Assume that the current starts at the positive end* (250 volt point), then the current passing through the upper section of the voltage divider will be made up of the currents passing through the entire resistor (this is the bleeder current), the current delivered to TAP 1, and also to TAP 2.

The power dissipated by the section of the voltage divider carrying more current will be greater per ohm of resistance. Since the voltage dividers are made in uniform size between the extreme terminals, the size (wattage) of the unit should be large enough to handle the maximum power in the tapped section where it will be present.

*When tracing through a practical circuit, it is sometimes more convenient to assume that the current flows from positive to negative. Whether this assumption is made, or the correct idea of negative electrons is used, you will obtain the right results provided you stick to one or the other idea in working out any one circuit.

SPECIAL POWER SUPPLIES

Certain resistance wire has an increase in resistance as it becomes warmer. But as the wire becomes warmer and the resistance increases, more opposition is offered to the current and less heat is created. In this way, a ballast control using such wire tends to keep the voltage supplied at a constant level.



Courtesy Superior Electric Co.

An illustration of an automatic voltage regulator incorporating a synchronous motor driven adjustable power transformer. The output voltage remains constant even with changes of power factor, input voltage, and current drain.

Although the automobile storage battery may need additional recharging at times, usually this battery is charged while the motor is running. A special generator is connected to the battery for this purpose and this generator is driven from the fan belt of the motor.

Observe that 24 watts is supplied to the dynamotor, while only 9.4 watts maximum can be obtained from the output.

tubes. It is possible to eliminate almost all variations and have constant voltage output with the aid of special circuits known as voltage regulators. Usually, special circuits using gas-filled tubes are employed.



Figure 141. Plug-in ballast or automatic line voltage regulator. Wound with special resistance wire which varies its resistance with the generated heat of passing current, this device maintains the voltage applied to a radio set within fairly narrow and safe limits.

Courtesy Clarostat Mfg. Co.

AUTO RADIO POWER SUPPLY. The early automobile radio sets used the storage battery incorporated in the car for a source of "A" battery power and provided space for carrying several 45



Courtesy Eicor, Inc.

Figure 142. Dynamotors are small converters usually designed to operate from 6 or 12 volt batteries, and supply D.C. voltage for the operation of radio receivers and transmitters in airplanes and Army mobile equipment.

volt "B" batteries. Since the six volt storage battery of the car is kept in a well charged condition by the generator which operates when the motor is running, the engineers tried to obtain all needed power from this battery. Small dynamotors were used. A dynamotor combines in a single case, a six volt motor and a high voltage generator. The dynamotor may be designed to operate from the 6 volt storage battery and have a current drain of 4 amperes. The high voltage delivered will be in the order of 180 volts, at 50 ma. The difference of power will be used up as friction and heat.

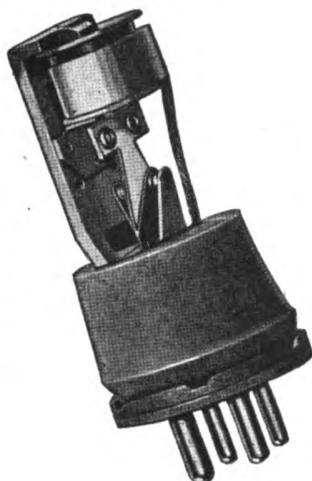
VIBRATOR. A transformer will work only with changing voltage. The voltage need not be of sine wave type, but it must be changing. If a transformer is connected to a six volt battery through a switch and this switch is closed and opened very fast, the D.C. voltage of the battery will be interrupted. The voltage will change

from zero to six volts many times per second and the transformer will operate. It is possible to produce this type of interrupted voltage even more efficiently with the aid of a special vibrator.

VIBRATOR ACTION

Figure 143. This is inside view of an automobile radio power supply vibrator. Notice the magnet at the top, the vibrator reed directly below the coil, and the two sets of contacts on each side of the reed. Many vibrators plug-in regular 4, 5, or 6 prong sockets.

Courtesy P. R. Mallory & Co.



The contact points of the vibrator unit are designed to *wipe* each other on contact. This action keeps the surfaces smooth and presents a large contact area for the passage of the current.

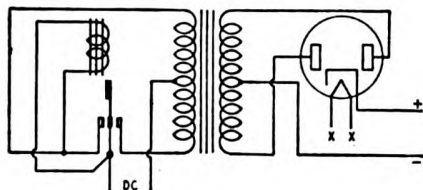


Figure 144. In a vibrator power supply, the low voltage is interrupted to permit the stepping-up of the voltage with a power transformer.

Examine the left hand side of the illustration above. Notice that the D.C. (6 volts in the case of most units) has one lead connected to the primary center-tap. The other side of the D.C. is connected to the center vibrating reed and also to a small electromagnet placed near this reed. Now trace the circuit through and you will see that the current passes through one-half the primary. Enough current goes through to make the small electromagnet attract the reed to the left, completing the circuit between the reed and the left-side terminal. This action *shorts* the electromagnet, but increases the current through the upper half of the primary. Now, since the electromagnet has lost its attraction, the reed will swing back all the way and make contact with the right-side terminal. The current will not be present in the upper half of the primary, but will now flow in the lower half and in the opposite direction. This is very much like the two loops of the A.C.

The reed is flexible and vibrates back to the center position. At that instant, the entire cycle repeats itself. This action takes place about 115 times per second, and we have a type of A.C. for the operation of our transformer. This transformer steps up the voltage to the required value and the balance of the power-supply is made up of the usual rectifier (shown) and filter (not shown).

BUFFER CONDENSERS. There are some special precautions to be taken in the design of vibrator systems. When the contact is made, there is such a sudden increase of current that a high voltage peak is induced in the secondary. Furthermore, sparks are likely to appear at the contacts. Various ways have been devised to eliminate

The shape of the voltage waves is almost square.

The vibrator power supply transformer must be designed for the frequency of the interrupted current.

SYNCHRONOUS VIBRATORS

The reason such high break-down voltage condensers are used in relatively low voltage circuits is due to the presence of high voltage transients. When inductive circuits are completed or broken suddenly (as in the vibrator circuit), instantaneous high voltage peaks result.

These contacts are insulated from each other, but the moving contacts may be common for these two sets. As you see from the diagram of the synchronous vibrator circuit, such arrangement of terminals is required.

Synchronous vibrators eliminate the need of a rectifier tube, but they are not as efficient as the non-synchronous types.

the interference caused by the vibrator. Buffer condensers are generally placed across the secondary and sometimes across the primary. The buffer condensers used in the primary may be .5 mfd. 600 volt types, one across each half. The buffer condensers in the secondary circuit may be .008 mfd. tested at 2,000 volts. Other manufacturers connect a center-tapped resistor across the primary. The buffer condensers will absorb the sudden charges and, thereby, improve the waveform. Yet this alone is not sufficient to insure noise-free reception. The supply filter may contain an R.F. filter in addition to the regular filter and the filament circuit may be filtered too. Also the filament circuit should not have any part in common with the vibrator circuit except the battery, of course.



Figure 145. Vibrators may be constructed with extra sets of contacts in order to handle greater current.

Courtesy P. R. Mallory & Co.

SYNCHRONOUS VIBRATOR. The armature of a synchronous vibrator closes another set of contacts which serve to rectify the current in the secondary. The figure shows this principle. When the armature moves downwards, it not only closes the primary circuit but

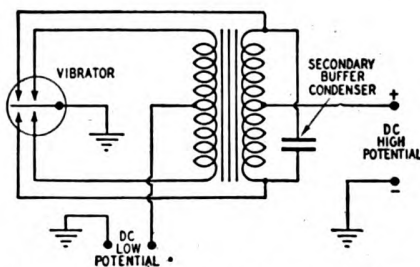


Figure 146. Full-wave power supply using a synchronous vibrator.

also the secondary; when it moves up, the other halves of both the primary and secondary are closed. A buffer condenser is again employed in the secondary to improve the wave form. The usual R.F. filters and the ripple filter are used as in the other vibrator system.

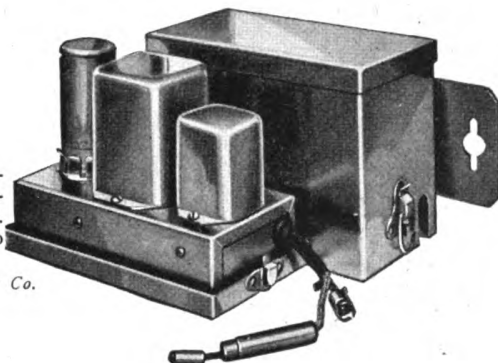
VIBRAPACKS. Since a six volt storage battery is available very often to serve as the source of power, special power packs are constructed to operate from this voltage and deliver different values of plate power. Such a power unit is called a *vibrapack* since it uses a vibrator. The vibrapack circuit is very similar to the power supply of an automobile radio set, but is able to deliver more

power. Some of these units use a non-synchronous vibrator and a rectifier tube. The circuit illustrated employs a synchronous vibrator. Let us analyze this circuit.

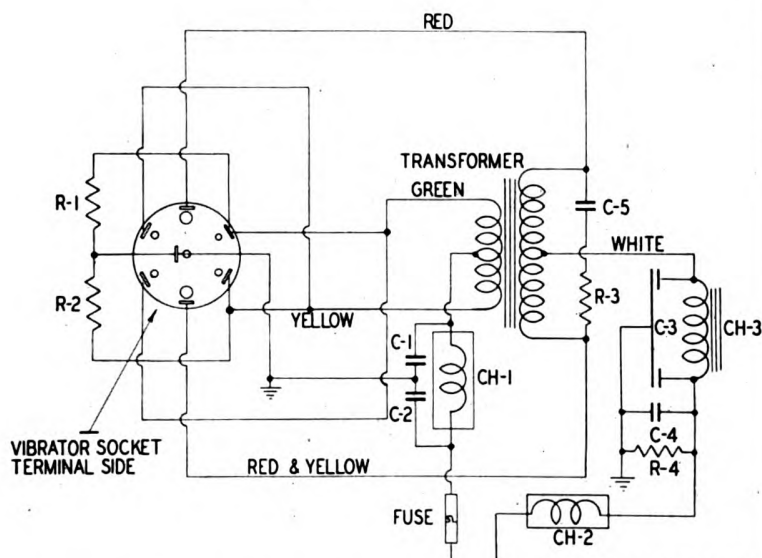
VIBRAPACK CIRCUIT

Figure 147. The vibrator type power supply designed to furnish D.C. voltage for a small radio transmitter.

Courtesy P. R. Mallory & Co.



The six volt input is connected to the circuit through a fuse which may be about 15 ampere size. Actually the unit may draw only 5 amperes, but if some fault develops in the circuit, the current may greatly increase and the fuse will burn out (melt and break the circuit) preventing damage to the equipment. The other side of the six volt supply is connected to the frame (ground) of the unit. The lead, close to the fuse, connected to the choke CH-2, is the positive side of the high voltage output. The negative connection of the high voltage is made to the frame.



Courtesy P. R. Mallory & Co.

Figure 148. A schematic diagram of a vibrator type power supply. The operation is explained in the text.

Except for the filter network consisting of the two C-2 by-pass condensers and the R.F. choke CH-1, the primary of the vibrator type transformer is connected in the usual fashion. Please understand that the center, grounded connection goes to the vibrating reed, while one set of stationary terminals of the vibrator is con-

Equipment designed for 6 volt operation is usually employed with an automobile storage battery which has one terminal grounded to the metal frame of the car. This explains why automobile radio sets, vibrapacks, and other units which operate from 6 volts, have their frame serve as the return terminal. Only one actual connection is needed. The circuit is completed through the contact of the metal chassis and the frame.

You may sketch in the above space the internal schematic view of the vibrator unit and the connections to the six prong socket.

ACTION OF THE VIBRAPACK

Shielding a vibrator power supply is essential. The sparking at the contacts plus the presence of inductance and capacity makes the equipment behave as a transmitter. The signals generated here must be kept out of the actual receiver or they will cause interference. Usually, each part employed in the vibrator power supply is shielded and the entire supply is also enclosed in a metal container.

The use of a special vibrator type circuit permits the changing 110 volts D.C. to suitable 110 volts A.C. to operate A.C. equipment. Rotary converters and *thyatron* tube equipment also may be used for the same purpose.

nected to the two sides of the transformer primary. The vibrator socket only is shown in the diagram; the vibrator is of the plug-in type. Notice that two resistors, R-1, are across each half of the primary of the transformer to reduce the arcing at the contacts.

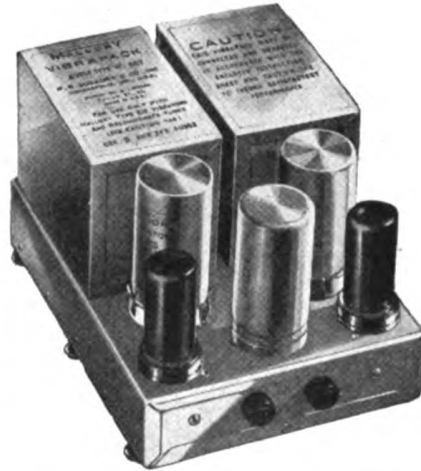


Figure 149. A high power vibrapack of the type described in the text. Notice that two rectifier tubes are employed and that three vibrators are used.

The secondary of the transformer is loaded by a resistor R-3 and a condenser C-5, also to reduce arcing. The choke CH-3 and the condensers C-3 form the regular power-supply filter. The rectification takes place in another set of terminals in the vibrator. The condenser C-4 is of small capacity and is used to by-pass any R.F. which may have been generated by the vibrator. Sometimes the larger size electrolytic condensers actually act as chokes to R.F. In general, it is a problem in vibrator power supplies to eliminate the R.F. generated; the units are carefully shielded and filtered for this purpose. The resistor R-4 is a small bleeder to stabilize the output. Be sure you understand the action of this unit before you go on.



Figure 150. Vibrator type power supplies are also constructed to convert 110 volts D.C. to 110 volts A.C.

Courtesy Amer. Television & Radio Co.

DRY PLATE RECTIFIERS. For rectifying A.C. at low voltages, chemically covered plates are well suited. When a magnesium treated disc is brought in proper contact with a disc of copper sulphide and a current passed so that a reaction takes place, this combination conducts only in one direction. This single direction conduction is similar to the action of a diode rectifier and can be used for the same purpose. Many battery chargers use dry disc rectifiers.



Figure 151. Gasoline-motor-driven generators are used to generate electric power for portable requirements.

Courtesy Eicor, Inc.

REVIEW QUESTIONS AND PROBLEMS. 1. Why is power needed for operating radio equipment?

2. Can batteries supply the power needed by any type radio unit? If your answer is yes, is such practice practical?

3. Explain the construction of a "B" battery.

4. How does a diode rectify A.C.?

5. What *number* tube can be used as a full-wave rectifier? Can this same tube be used as a half-wave rectifier?

6. If a power supply without a filter is used with a radio receiver, what fault will be noticeable?

7. What factors must be considered in choosing a power transformer? Can a 25 cycle transformer be used for 60 cycles?

8. How are chokes rated?

9. Why do some sets have a voltage-divider?

10. How does a vibrator change D.C. to suitable current for operating a transformer?

11. Why are buffer condensers needed?

12. What advantage is there to the synchronous vibrator?

13. Can full-wave rectification be obtained by using several dry disc rectifiers? Can you sketch the circuit?

4. Explain this action detail. Use sketches.

5. Refer to the tube characteristic charts and observe what facts are stated about rectifier tubes that are not presented for other vacuum tubes. You probably know a few rectifier tube types or can refer to page 119 for suggestions.

6. If you have a radio available for experimentation, you are safe in disconnecting the two filter condensers employed in the power supply. Only one lead of each condenser need be broken. What happens to the operation?

LESSON 11

Audio Amplifiers and Accessories

This lesson presents important facts on the fundamentals of *public address* which is the special name for electronic amplification of sound.

In this lesson especially, you may find many new words not familiar to you. These words should be looked up in the dictionary. We suggest that you write the meaning in the margin alongside the difficult word so that you will be reminded of the definition.

The letter F. stands for the Fahrenheit thermometer measurements. This thermometer is used in the United States. At 32 F., water freezes, and at 212 F., water boils.

SOUND TO ELECTRIC ENERGY. In order to amplify sound, speech or music, the sound energy must be changed to the equivalent electrical energy. Once the sound takes the electrical form, it may be handled by radio equipment and, finally, in the receiver changed back to sound energy. We must learn a little about sound and about the devices used to change sound to electrical energy.

NATURE OF SOUND. Sound must be conducted through some medium. In general, solids are very good conductors of sound, but porous materials such as cotton, sawdust, etc., are poor conductors. Liquids are better media for sound conduction than gases. For us, the air is the most useful medium for sound conduction. The physical meaning of sound is the existence of a disturbance in the air or other media consisting of a succession of alternate waves of *compression* and *rarefaction* that tend to travel outwardly in all directions away from a vibrating body.

The velocity or speed of sound in air has been carefully determined. In air at 32° F. temperature, the velocity of sound is 1,090 feet per second. As the temperature rises, the velocity also increases. This rate of increase is about one foot per second per degree F.

The velocity of sound in many other media also has been determined. In water, it is approximately four times as great as in air. The velocity in any medium is inversely proportional to the square root of the density. A solid having greater weight per unit volume, all other factors being equal, will have lower velocity. The velocity is also directly related to the elasticity of the material. The elastic constant of any substance is the degree that the substance resists deformation. Soft rubber has a very low elastic constant.

Vibrations are transverse or longitudinal. Water waves are transverse to the line of motion. There is no forward movement of the water itself, but there is a rising and falling motion as the water wave advances. Any particle of water on the surface will rise and fall, but will move neither forward nor backward. If the motion of the particle was plotted against time, it would describe a curve similar to the wave. The wave itself, of course, results because a great many such particles move up and down in the correct order.

When a body vibrates, the air immediately in front is first compressed and then released. In this way, a series of condensations and rarefactions is produced. This train of waves is longitudinal, since it takes place in the direction of motion. There is but little movement of the air forward since each pulse communicates its energy to the air directly in front.

Any sound wave, no matter how complex, may be shown to be made up of a number of simple sine waves. One of these is the original wave and the others the harmonics or overtones of this wave. The character of sound depends only on three things: (1) pitch, (2) loudness, and (3) quality.

The pitch is the characteristic which enables us to distinguish between notes of various frequencies, the high, medium, low-frequency notes for instance. Pitch is a direct function of the frequency of the vibrations. In simple and complex tones, the pitch is usually determined by the fundamental frequency. In some complex tones, however, this is not the case as shown by recent research work.

The second characteristic, loudness, depends on the energy of the vibration. Our ears respond to loudness in logarithmic proportion and not in direct ratio. A ten-fold increase of loudness would appear to the average listener only as twice as loud. Signals of equal intensity but of different frequencies usually appear to be of different loudness.

Quality of *timbre* of sound is the characteristic that enables us to distinguish sounds of identical pitch and loudness but produced by different people or instruments. Every one knows that the same notes played on a violin and piano equally loud will sound entirely different. This is because both are of the same pitch and have the same fundamental frequency, but the harmonics present in each greatly differ in number and their relative intensities.

ACOUSTICS. *Acoustics* is that branch of science that deals with the action of sound. All sounds created proceed outwards in spherical waves until they strike the boundaries of the room. Upon striking the walls, sounds are absorbed, reflected, and transmitted in varying amounts depending upon the character of the walls. Sound energy is diminished with each reflection because of the absorption, and this finally results in the sound dying out. Continuous reflection has the advantage of loudness, but always introduces prolonged existence of each sound. This prolongation, or *reverberation*, is the most common acoustic fault found in auditoriums.

A person talking in an auditorium having a high reverberation time can be understood only with difficulty. Each sound instead of dying out quickly persists for some time, so that spoken words blend with their predecessors and set up a mixture that produces confusion. This acoustic difficulty may be corrected by the introduction of sound-absorbing materials to reduce the reverberation time.

In the case of music similar, but less objectionable, effects are produced because of prolonged reverberation. Good acoustical conditions are obtained when sound rises to a suitable intensity, with no echoes or other types of distortion, and then dies out quickly enough not to interfere with the succeeding sounds. This is a very hard condition to fulfill, but considerable departure from the ideal is not very objectionable to an average listener.

CARBON MICROPHONE. A microphone is a machine for transforming the sound waves into corresponding electrical energy. How truthfully it performs this task is the test of its excellency. The carbon microphone was commonly used in the early days of broadcasting and is still the type employed in telephone work. A cup containing small carbon granules is so placed and mechanically connected to a diaphragm that sound vibrations, striking the diaphragm, cause fluctuations of the diaphragm and of the carbon granules. These granules are compressed as the direct result of the sound waves striking the diaphragm. The resistance of the carbon granules (collectively) varies as a function of the sound

Harmonics of any frequency are frequencies which are multiples of this fundamental frequency. For example, a 400 cycle note, may have a second harmonic of 800 cycles, a third harmonic of 1,200 cycles, etc.

Absorbed: consumed, used up, killed.

Reflected: bounced off, returned.

Transmitted: passed on, gone through.

Reverberation time of an auditorium may be shortened with the aid of sound absorbing material. Drapes and carpets help. The wall and ceiling may be lined with special sound absorbing blocks.

TYPES OF MICROPHONES

This current is only the exact electrical equivalent of the sound in the practical sense. Certain amount of distortion and change is introduced by the microphone.

The impedance of each microphone button, acting as a voltage generator in conjunction with the battery, for the average audio frequency handled is about 200 ohms. The transformer is designed to match this impedance to the secondary circuit. Although the grid circuit theoretically presents an infinite impedance, because of leakage in the transformer terminals and capacity effects, the actual impedance is in the order of 100,000 ohms.

By upper end of audible frequency range we mean the high audio frequencies not used for radio work.

The condenser microphone is interesting only from the historical point of view.



Astatic crystal microphone.

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waves. Since the resistance varies, the current, passing through the microphone and supplied by a battery, also varies. This current is an exact electrical equivalent of the sound reaching the microphone. In the two-button microphone, one button is placed on each side of the diaphragm and so operate exactly out of phase. This electro-acoustical push-pull arrangement cancels out the even-order harmonics and improves the quality of reproduction.

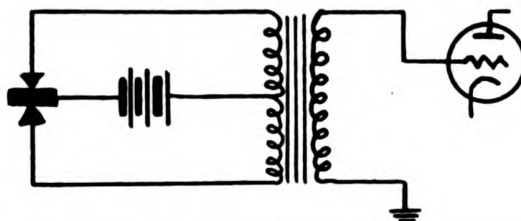


Figure 152. A circuit of a double-button microphone. Notice how the unit is connected to the center-tapped primary of the microphone transformer. The secondary is designed to match a high impedance and may be connected directly to the grid of the first tube used in the audio amplifier.

The thin metal diaphragm will resonate at a certain frequency and cause an increased undesirable output at this audio (sound) frequency. The better grade microphones have their diaphragms stretched so that resonance occurs at the upper end of the audible frequency range. This bad feature may be further reduced by air damping. The output of a carbon microphone is larger than that obtainable from other units. You will learn about decibels later in this chapter and will then understand what we mean when we say that this microphone has an output of about minus 40 decibels. The output impedance of each button is 200 ohms, and a transformer is used to match this to the equipment used.

CONDENSER MICROPHONE. At one time the condenser microphone was very popular, but it is not used at present. If a variable condenser is connected to a source of voltage, the charging current will vary with changes in the capacity. The diaphragm of a condenser microphone constitutes one of the plates of a condenser, while the fixed back plate acts as the other plate. The capacity so formed is in the order of only 200 micro-microfarads, and the maximum variation in capacity is only 0.01%, that is about .02 micro-microfarads, a very small amount.

Usually the head of the condenser microphone contained a built-in pre-amplifier to bring up the output signal to the level delivered by a carbon microphone.

CRYSTAL MICROPHONE. The crystal microphone employs a piezo-electric crystal as a generating element. A crystal when subjected to stresses of sound waves produces corresponding electrical changes in current which is generated by the crystal element. The output level of a crystal microphone is, of course, much lower than that of a carbon microphone, usually in the order of -60 db., and requires either a suitable pre-amplifier or a main amplifier of a high gain type. The crystal microphone has absolutely no background noise and the response is not effected by the position of the microphone or by reason of moving it about while in use.

By using specially shaped and treated housing cases for crystal

elements, it is possible to obtain crystal microphones which have desirable directional characteristics. It is an advantage, for example, to have a microphone which does not pick up sound originating from the side facing the audience.



Figure 153. Crystal microphones are commonly used for public address and broadcasting requirements. The microphone itself is mounted on a desk or floor stand.

Courtesy, Shure Bros.

VELOCITY MICROPHONES. The velocity microphone has been more recently developed and because of its excellency is finding extensive application. Velocity microphones have an output of about the same value as the output of crystal types, and may be obtained in high-impedance types for direct coupling to the control grids of vacuum tubes.

The velocity microphone has highly directional qualities and will not pick up background noises. This greatly assists in reducing the possibility of reproducing undesirable noises. This type of microphone further has no internal "hiss noises" and possesses quite flat response characteristics over a wide audio frequency band.



Figure 154. The dynamic microphone illustrated has desirable directional pick-up qualities.

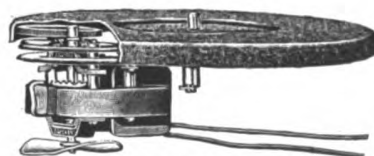
Courtesy Shure Bros.

Microphones, in general, are mounted on suitable floor or table stands. Ring and spring mounting is used for carbon microphones while other types screw directly on the stand.

PHONO-PICKUPS. A pickup arm may consist of a permanent magnet within which is pivoted a coil of wire directly connected to the needle. As the needle works along the groove of a record, the unevenness of the grooves sets the needle in vibration. Since the needle is connected to the coil by mechanical means, the mo-

VELOCITY MICROPHONE

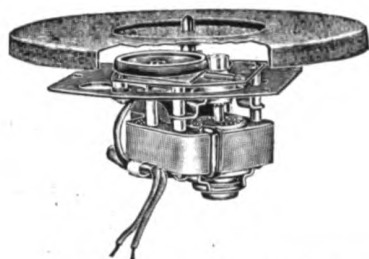
Most modern microphones mount directly on floor and desk stands. The stands have threaded male ends while the microphone housing has female threads. Adapters are available to match the microphone to a stand which may have different size threads or pipe size.



Courtesy Alliance Manufacturing Co.

Cut-away view of a phono motor and turn table. The small fan circulates air to keep the motor cool.

PHONOGRAPH PICKUPS



Courtesy Alliance Manufacturing Co.

An illustration of another rim driven phono motor and turn table. The majority of record players are designed for 78 R.P.M. records. Some special records are made to revolve at $33\frac{1}{3}$ R.P.M. and require special speed phono motors, but the pickups, of course, are the same for both types of records. Certain motors, by means of mechanical gears or special windings on the motor, can be made to rotate at either speed.

Mathematically the relationship between gain or loss of audio power, compared in terms of decibels, is:

$$DB = 10 \log_{10} \frac{P_{out}}{P_{in}}$$

This means that the gain or loss in decibels is equal to ten times the logarithm (to the base ten) of the power "out" divided by the power "in."

tion is transferred to the coil which, in moving, cuts the lines of force of the permanent magnet. A current is set up in the coil. This current corresponds to the recorded sound.

Phono-pickups of this type are called magnetic and may be obtained in high-impedance output types for direct connection to the input control grid of the vacuum tube used as an amplifier. Some of the older magnetic pickups are of low impedance types and must be matched with suitable transformers to the input.



Courtesy Astatic Corporation

Figure 155. Crystal pickups are used in record reproducing equipment.

Crystal pickups are very similar in operation to crystal microphones, but have the needle instead of the diaphragm actuate the crystal element. Crystal pickups develop greater output than most magnetic types and are always of the high impedance type.

INTENSITY OF SOUND. The sound intensity of an explosion is so many times greater than the sound of a pin dropping in a quiet room, that the human ear *adjusts* these levels to each other in a different proportion. When sound is actually ten times louder by the measurement of power in each case, the sound will appear to a human listener only as twice as loud. A convenient way for measuring sound or any other energy related to the auditory sense is to use the logarithmic unit called the decibel and abbreviated DB.

It is best to calculate the gain or loss in decibels by using a table rather than the exact mathematical formula. To use the table below, first get the ratio of the powers under consideration. If there is a power gain, the ratio will be a number greater than one.

Gain in DB	Power Ratio	Loss in DB	Power Ratio
40	10,000	0	1.
35	3,162	1	.8
30	1,000	2	.6
29	800	3	.5
26	400	4	.4
23	200	5	.32
20	100	6	.25
15	32	7	.2
12	16	8	.16
10	10	9	.12
9	8	10	.1
8	6.3	11	.08
7	5	13	.05
6	4	15	.03
5	3.2	17	.02
4	2.5	20	.01
3	2	25	.003
2	1.6	30	.001
1	1.3	35	.0003
0	1	40	.0001

If power is lost, the ratio will be a quantity less than one. Not all ratios are listed in the table, but the closest one to the value you need, will give you the answer accurate enough for practical work.

If power is increased from 2 watts to 64 watts, the ratio will be 32. Please notice that to obtain the ratio, you divide the output power by the input power. Looking up the gain of 32, you find this corresponds to a gain of 15 DB.

Of course, this table is also applicable when the gain or loss in decibels is known and power ratio is required. For example, in passing through a single audio stage the signal is increased 20 DB; what is the power ratio of the output to the input? An increase in 20 DB is a gain in 20 DB, and looking this up in the table, we find the corresponding power ratio equal to 100.

Since DB is always a ratio, when we speak of an amplifier as having so many decibels gain, we assign an arbitrary level of comparison. Usually 0.006 watts is taken as this figure. If one amplifier has 75 decibels in comparison with a given arbitrary level, while another has 60 decibels in comparison to this same level, the first has (75-60) or 15 DB more gain.

The transmission unit is employed to express any ratio of power, mechanical loss or gain, etc. related in some way to the auditory sense. The gain in voltage may also be considered in terms of decibels, but the voltages must be considered across equivalent impedances. In case you are considering voltage ratios and use the table above, the answer in decibels must be doubled. For example, a voltage ratio of 100, corresponds to 40 DB (and not 20), and the voltages must be measured across equal impedances.

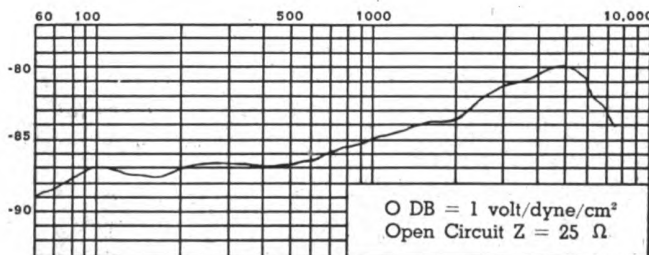


Figure 156. The output of a good quality microphone varies a little when used at different frequencies. The graph illustrates the output level of a good quality velocity microphone.

VOLTAGE AMPLIFICATION. Once sound is converted to electrical energy it is of very low intensity and must be increased or amplified. Vacuum tubes are ideal for this purpose and are used extensively in circuits known as audio amplifiers. We will first discuss the circuits which amplify the signal voltage and feed this voltage to the next stage which, in turn, also operates from a voltage signal alone and does not require power. Later we will explain the function of *power* amplifiers which are used to deliver actual audio power to loudspeakers.

We have in the figure a curve which represents the characteristics of a vacuum tube with a fixed plate voltage. You will notice that the vertical scale represents the plate current, while the horizontal scale represents grid voltage. As the grid voltage becomes more negative (to the left), the plate current is diminished.

INTENSITY OF SOUND ENERGY

In some instances, a comparison level of .001 watts is used instead.

This doubling results from the mathematical fact that power is a function of the voltage squared; i.e.

$$W = \frac{E^2}{R}$$

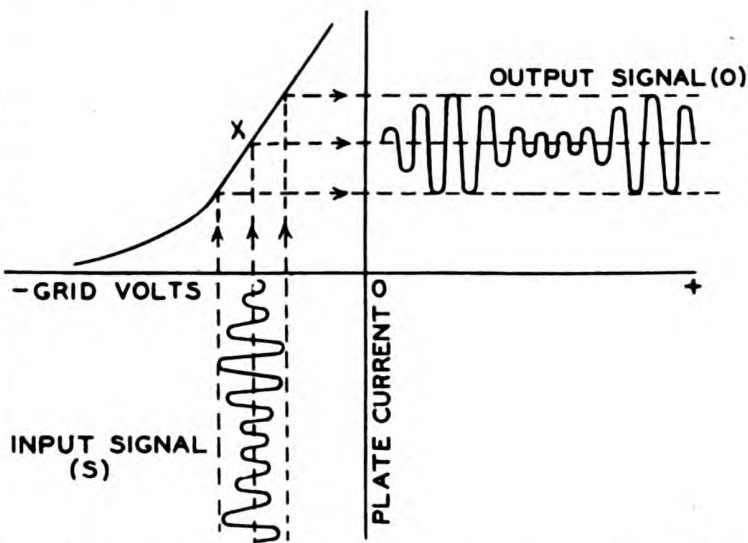
The basis for sound comparison also can be made on the assumption that 0 DB is equivalent to the development of a certain voltage with a given air pressure. For example, in the case covered by the graph, 0 DB is equal to the development of a voltage change of 1 volt with the air pressure of one dyne per square centimeter of surface.

Any amplifying stage requires some power in the form of the exciting signal. However, this power is so trivial that, for practical considerations, we can assume only a signal *voltage* is needed. Of course, the real power needed for operation of the stage comes from the power supply.

VOLTAGE AMPLIFICATION

To fix these ideas more clearly, assume that the tube is operated with minus 5 volts on the grid. With no signal, the voltage of the grid (in respect to the cathode) is -5 . For simplicity, we will assume that the signal is a sine wave having a peak value of 3 volts. When this signal, for an instant or so, reaches a peak of positive 3 volts, the actual voltage on the grid will be the algebraic sum of these voltages, or -2 volts. At another instant, the signal may reach its negative peak of 3 volts. At that moment, the grid will have a potential of -8 volts.

Notice the incoming signal represented by a succession of waves as shown in the lower left hand corner. This incoming signal will vary the fixed grid voltage, at times making it more negative and at other times making it less negative. The operating point X, therefore, will shift up and down the characteristic curve in accordance with the incoming signal.



Courtesy RCA

Figure 157. Please observe that the input signal will change the grid voltage on the control grid of a vacuum tube. This in turn will vary the plate current and produce a larger voltage change across the load impedance.

This changing of the grid voltage will correspondingly vary the plate current, and the actual current can be represented by a similar but larger set of waves marked, "Output Signal."

If this variation in current, which you understand is an exact duplication of the incoming signal, can be used to produce a voltage variation across the plate resistor or impedance this new voltage will be larger than the original signal. In this manner amplification will take place.

TRANSFORMER COUPLING. Let us assume that the radio tube we have been considering is so connected that the plate current must pass through an inductance in order to reach the plate. This simply means that a coil is connected between the B-plus terminal and the plate connection of the vacuum tube. Since audio frequencies are involved, the inductance will have an iron core.

The current variations, which are occurring because of the incoming signal, will produce a changing voltage drop and set up a changing magnetic field in accordance with these variations. The voltage so developed will be larger than the incoming signal by a ratio a little less than the amplification factor of the vacuum tube. For example, if the vacuum tube has a μ of 20, the gain will be in the order of 17.

In order to isolate the positive plate voltage from the tube grid of the next stage, a transformer is employed. To construct a transformer from the plate inductance we have described, it is only necessary to place the secondary coil on the same core. In this fashion, the proper grid bias can be applied to the next stage, and

Current passing through an impedance produces a voltage drop in proportion to the current.

at the same time the plate voltage of the preceding stage can be kept out of the grid circuit. The voltage developed in the primary inductance will be transformed to the secondary (grid) inductance. The turns ratio may be made about 3 to 1, and a further step up of the voltage by a factor of three will result. Besides doing all this, an interstage coupling transformer will also, to a large degree, match the impedance of the plate circuit of one tube to the grid circuit of another.

Transformer coupling always produces some audio distortion and the tone quality from equipment using inexpensive transformers is not as good as resistance coupling which we will describe next.

CLASS OF OPERATION. By referring back to the characteristic curve on the previous page, you will see that under all conditions of operation considered, some plate current is present. With no signal the current is indicated by the operating point X. As the signal is impressed, the operating point may shift, changing the plate current, but always permitting at least some small value of plate current to exist. If plate current is always present in a circuit, the tube is operated in *Class A*.

If the operating point is located at the extreme left hand side of the curve making the plate current almost zero with no signal, this is known as *Class B* operation. You will notice that, under this condition, if the signal makes the grid *more* negative than this assumed cut-off point, no plate current will be present. However, when the signal is positive, the operating point will shift sufficiently to the right, from this cut-off point, to permit plate current.

Sometimes vacuum tubes are operated with the bias twice the negative amount required to stop plate current, i.e. twice cut-off value. In such operation, only during the extreme peak positive operation of the signal does the plate current flow. This means that during the greater portion of any cycle of the signal, no plate current is present. This type of operation is known as *Class C*, and is used in transmitters.

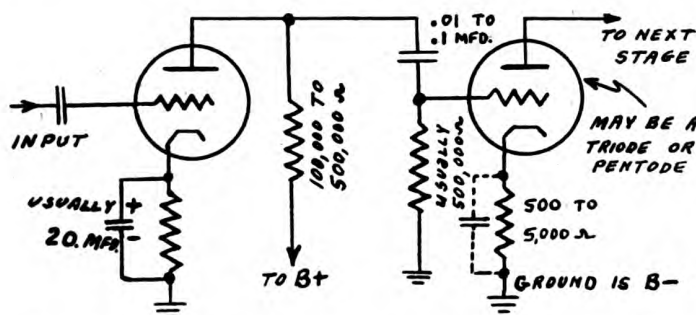


Figure 158. Resistance coupled stages are used in the audio section of radio receivers. The value of the parts employed is not critical. Resistance coupling gives better quality than is obtainable with inexpensive inter-stage transformers.

RESISTANCE COUPLING. For economy reasons and for better tone quality, the plate circuit of a voltage amplifying tube is loaded with a resistor. Usually a resistor of 100,000 or 250,000 ohms is connected from the plate of the vacuum tube to the positive potential of the plate supply. This resistor, in other words, replaces the primary of the interstage transformer.

The voltage drop across this resistor will be a function of the plate current, and will, therefore, vary with the signal. Please

A, B, OR C CLASS OF OPERATION

In the usual triode, a plate load of about 10,000 ohms will give best results. The grid input impedance is in the order of 100,000 ohms. These impedances must be matched with the transformer.

The operational point of a *Class A* amplifier is selected to permit the operation over a straight portion of the characteristic curve.

With *Class B* operation, the plate current is practically zero with no signal. Additional negative potential caused by a negative peak of the signal will make the grid more negative and still keep the current at zero.

The object of circuits using *Class C* operation is to shoot out pulses of plate current at the extreme positive peaks of the signal voltage.

The plate current of the first tube of the circuit produces a voltage drop across the plate load resistor. (This current must pass through this resistor and an IR drop will result.) As the current changes (due to the action of the signal on the grid), the voltage drop across this plate resistor will also change. This changing voltage drop is re-impressed upon the grid of the tube in the next stage.

RESISTANCE COUPLING

These voltage relationships are very important and must be clear to you. The amplifying action of the stage and the phase relationship are explained in these paragraphs.

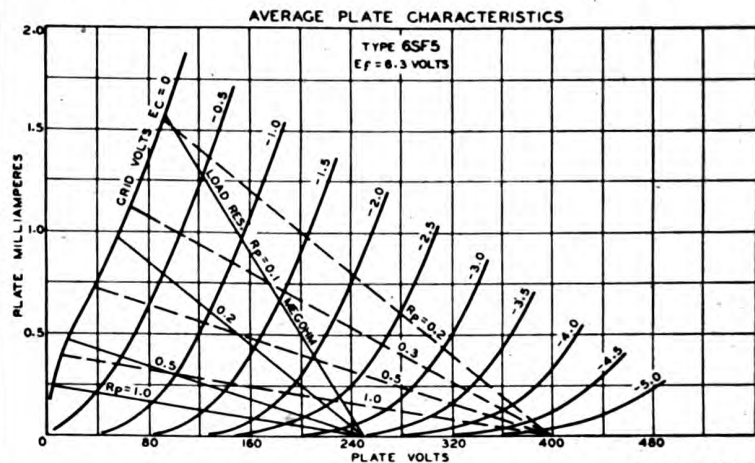
For the practical technician working with radio and electronic circuits, the operating data for different vacuum tubes employed can be found in tube manuals.

What happens if the grid resistor is too small? Since the signal developed across the plate resistor (refer to page 135, Figure 158) is placed across the plate coupling condenser and grid resistor in series, the available voltage will divide itself. The condenser has a definite value of capacitive reactance at any one frequency, and this reactance (impedance) is in series with the grid resistor. If the grid resistor is too small, only a small fraction of the total signal developed will excite the grid of the next stage and the circuit will have poor bass response since the capacitive reactance will be higher for low frequencies.

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understand that when the grid signal of the tube is becoming more positive, the plate current will increase, and so will the voltage drop across the resistor. Since the supply voltage is fixed, the available voltage on the plate of the tube will become smaller. The voltage on the plate is always equal to the plate supply voltage minus the voltage drop in the plate resistor.

If a voltmeter is connected across the plate resistor, the negative terminal will be at the side of the resistor which is connected to the plate. If the voltage drop across the plate resistor increases, this point actually becomes more negative. You can see, therefore, that a positive, increasing grid-signal will produce a greater current, greater voltage drop, greater negative voltage at the point of the plate resistor which is near the plate of the vacuum tube. From this action, you can see that the tube apparently reverses the direction of the signal and also amplifies it at the same time.



Courtesy RCA

Figure 159. Average plate characteristic curves may be used to determine the operation to be expected under different conditions. The illustration shows the expected operation with different load resistances.

The next audio stage may be connected directly to this point of the plate resistor, but it needs to be isolated to keep the D.C. plate voltage out. For this purpose, the plate coupling condenser is connected between the plate of the vacuum tube we have described, and the next stage tube control grid. This condenser should be rated at 400 or 600 volts and may be almost any size between .01 and .1 mfd.

The grid of the tube in this next stage must have a return circuit to the ground (chassis) in order to permit the leaking off of electrons. The grid resistor is used for this purpose. This resistor may be of small power rating, and in most circuits has the resistance value from 250,000 to 1,000,000 ohms. This resistor is connected from the grid of the tube to the ground.

HOW GRID BIAS IS OBTAINED. In radio receiving tubes, the grid must be biased to a negative potential. The value of this voltage must be such that it will keep the grid negative even on the most positive peaks of the incoming signal. This means that the bias voltage must be greater than the strongest signal. In the experiments we discussed, we used a small battery to provide the grid voltage. Such a battery is called the C battery. Since the grid circuit does not pass current, the battery will last a very long time. However, even when not used, batteries age and become

dead with time. For this reason and because we want our radio receivers to be completely A.C. operated, battery bias is not ordinarily employed.

In radio sets using a voltage divider, it is possible to connect a tap delivering some small positive voltage to the cathode of the tube to be biased. A lower tap (representing a negative voltage by comparison) is connected to the grid return which may be the grid resistor in a resistance-coupled stage. This arrangement automatically will supply a negative voltage of the chosen value to the grid in respect to the cathode of the tube.

In some sets, the filter choke is placed in the negative leg of the power supply. This choke has D.C. resistance and will produce a voltage drop in relationship to the current the set draws. Please understand that the average plate current in a *Class A* tube, as used in radio receivers, is almost constant. This means that the total plate current of the radio set operating is almost a constant. The voltage drop across the choke may be used to supply the needed bias to one or more tubes. If the entire voltage drop is not needed, a part of the drop may be *tapped-off*.

The self-biasing method is most often used in radio receivers. In such circuits, the grid return is connected to ground (chassis) which also is the negative side of the plate supply. The cathode is connected to the ground through a suitable resistor. Now the plate current passing through the tube must go through this cathode resistor to the plate supply negative terminal (the ground in our circuit). When current passes through a resistor, it produces a voltage drop which is equal, at all times, to the current multiplied by the resistance. For example, let us say the tube we are using has a plate current of 5 ma. or .005 amperes, and the resistor used is 2,000 ohms. Multiplying these, we obtain a voltage drop of 10 volts. This is the actual voltage across the cathode resistor.

Now one side of this resistor is connected to the cathode of the tube. The other side of the resistor is connected to the ground—the very same point where the grid return of the tube is connected. So you see that the voltage across this resistor is impressed on the grid in relationship to the cathode. Please notice that no voltage drop occurs in the grid resistor (the one which is usually 250,000 ohms to 1 megohm) since the grid does not pass any current.

We see that there is a voltage between the grid and cathode, but is the grid negative as needed? We already mentioned that the ground is the most negative point of the power supply. Of course, the plate of the tube is positive. Since the cathode is between the plate and ground, it is more positive than ground. But ground potential is also the grid potential, since they are connected together through the grid resistor. And so the grid is more negative than the cathode, as required.

The voltage across the cathode resistor, which is our bias voltage, is a direct function of the plate current at the instant. This plate current is varying up and down with the signal. The rate of this up and down change depends on the frequency of the audio signal being received. But we want the bias to be fixed and not change with the signal. To accomplish this, we by-pass the signal variations around the cathode resistor with a by-pass condenser. In practice, in the audio stages, this cathode by-pass

This is the important method of obtaining bias.

Since this bias voltage in reality is supplied by the power supply, the voltage of the power supply serving the plate circuit is actually reduced by the amount lost in the cathode bias resistor.

The voltage drop produced in any resistor is the product of the resistance by the current. If the current is zero, the product of any resistance by zero, is zero.

The plate current passes through the tube and, since the electrons originate from the cathode, the same current must pass through the cathode resistor at every instant.

USING BIAS CELLS

If batteries were used for the same purpose as bias cells, they would require periodical replacement, while the bias cells last indefinitely.

Since the circuits used with bias cells usually have a high resistance, the additional equivalent 25,000 ohm resistance of the cell does not alter the function of the circuit.

condenser is large, about 10, or 25 mfd. An electrolytic condenser may be used since the cathode is always positive in respect to the ground. The working voltage required is about 35 volts. If the by-pass condenser is omitted, a certain amount of degeneration and distortion will result.

BIAS CELLS. The P. R. Mallory & Co. manufacture special units which are excellent for providing the required bias voltage. The fixed bias obtained from these units is similar to that obtainable from batteries and is, therefore, superior to the cathode self-biasing method in some respects. These units are called bias cells and are small acorn-shaped devices about $\frac{5}{8}$ " in diameter. The black disc is the positive electrode, the metal container is the negative electrode. These cells are made in two types to deliver 1 volt or $1\frac{1}{4}$ volts. The cell is strictly a potential, or voltage, cell and should not be used in circuits where there is flowing current. No current, of course, is present in the grid circuit of a negatively biased tube. The characteristics of the cell are unaffected by superimposed A.C. as high as 360 microamperes of any frequency. The bias cells are non-reactive at audio frequencies and behave like a resistor of about 25,000 ohms, which may be assumed to supply the voltage of the cell.

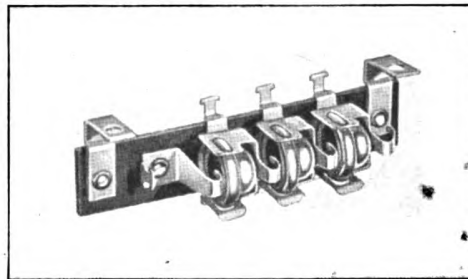


Figure 160. Several Mallory bias cells may be used in series to give higher voltage than is obtainable from a single cell.

Do not measure the voltage of the bias cell with an ordinary voltmeter. Use a vacuum tube voltmeter if measurement must be taken. If the cell is connected accidentally so that it supplies current, it will be dead for some time, but the voltage is usually restored after several hours if the cell is left out of the circuit.

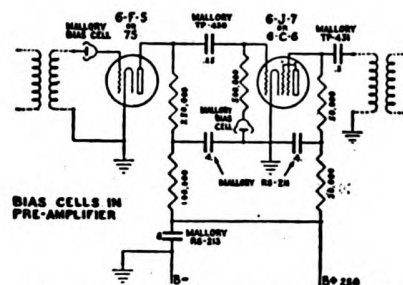


Figure 161. This resistance coupled amplifier uses bias cells to furnish the required grid bias.

Please examine the circuit of the pre-amplifier illustrated. Notice that transformer input to the amplifier is used. The trans-

formers shown are of audio types although the core is not shown in the symbol. Observe that the cathodes of both tubes used are at ground potential, and that the grid bias in each instance is supplied by a bias cell. Several bias cells may be connected in series for greater bias voltage. Special holders are available to mount one or more bias cells.

DISTORTION. Even the best amplifiers introduce some distortion. A perfect amplifier would reproduce the input signal exactly, increasing the amplitude (intensity) by a definite factor. If the input is a sine wave, the output will also be a sine wave of greater height. The various sections of the wave will be multiplied by the same fixed amount, and all sections will receive the same "multiplying" effect. Vacuum tubes and other electrical devices do not behave in the same way to voltages and currents of different magnitudes. For example, the portion of the sine wave corresponding to the smaller instantaneous voltages may be amplified ten times, but the stronger passages will be amplified only eight times, and the very peak of the sine wave may be amplified only seven times. The resulting curve (representing the output voltage) will not be a sine wave. The amplitude (height) of the original sine wave has been multiplied by various factors (from 10 down to 7) depending on the instantaneous intensity. Distortion of the wave resulted and this type of distortion is called *amplitude distortion*.

Vacuum tubes, especially those used as audio power amplifiers, introduce *harmonic distortion*. Harmonics are frequencies which are integer multiples of the fundamental frequency. For example, 800 cycles is the second harmonic of a 400 cycle fundamental. When vacuum tubes are operated over the curved portion of the characteristic curves, harmonics are introduced in the output, although the incoming signal may be a pure sine wave fundamental. Usually the second harmonics are strongest and the intensity of the other harmonics diminish with their order. The stronger the incoming signal, the greater the portion of the characteristic curve is used and, since the ends of the curve are *least* straight, the strong signals produce most of the harmonic distortion. Usually 5% harmonic distortion is permissible in commercial radio receivers. By the percentage of the distortion, we mean the percentage of the output which is of the undesirable harmonic frequencies.

Many audio circuits using capacitors and inductors have the amplification vary with the frequency of the signal. The amplifier stage itself acts as a sort of tone control changing the intensity of the output with the frequency of the signal. A poorly designed stage, for example, may amplify very little at frequencies under 200 cycles, have the amplification increase gradually from this value to 3,000 cycles, drop sharply at this value, then rise quickly to very much greater amplification as the frequency is increased further. You recall, of course, that a good amplifier will amplify the same amount for all frequencies encountered. This type of distortion is called *frequency distortion*. Frequency distortion always produces an undesirable phase shift and may also be called phase distortion.

TRIODE POWER AMPLIFIER. In any power amplifier the object is to develop power with little distortion. We have already studied how a vacuum tube is used to produce voltage amplification. In order to produce as much power as possible, the tube must be op-

DISTORTION IN VACUUM TUBES

You will notice that this discussion of audio distortion is based on the effects on a sine wave. This is permissible since it is possible to represent any complex wave as a sum of sine waves.

The different order harmonics are present in various proportions. Usually, as the order of the harmonics increases, their intensity diminishes.

Midget type radio receivers having a single audio output tube of the pentode type may have as much as 10% harmonic distortion.

Frequency distortion is due to changing values of impedance which condensers and inductors present to various frequencies.

AUDIO POWER AMPLIFIERS

This increase in current at certain instances exactly corresponds to the decrease at corresponding instances a moment later in the cycle. The instantaneous currents integrated over a period of time will correspond to the average *no-signal* current.

A generator will deliver maximum power to a load of a value exactly equal to the generator impedance. If power is of no importance (as in voltage amplifiers), a load having higher impedance (usually a resistor) will produce a larger voltage drop.

Check the data for a few power type pentodes. See, for example, types 41, 47, 25A6.

Almost any pentode may be turned into a triode by connecting together the screen grid and plate.

erated with as much plate current change as possible. However, to keep distortion to a minimum, only a little of the extreme parts of the characteristic curves may be used. The center, straight portion is used primarily. The operating point (no signal point) is in the center representing the plate current with no signal. With signal, the plate current may almost double on positive peaks, and be reduced almost to zero on the negative peaks. Over a period of time, however, the average plate current remains constant. This is why a meter in the plate circuit will show no change in the plate current except for minute variations due to harmonics.

The power amplifier stage must be driven with a signal which has peaks equal (almost) to the bias voltage. This will cause the instantaneous grid voltage to vary from zero to twice negative bias voltage on peak signals. Since triode power amplifier tubes have low amplification factors, the signal voltage needed is quite high. The triode power amplifiers have low power sensitivity. Types 45, 2A3, 71A, are power amplifier triodes; find their amplification factor and power output rating.

The power amplifier tube acts as an A.C. generator and must be correctly loaded to deliver maximum power output with the least distortion. Usually power amplifier triodes are loaded with an impedance which is exactly equal to their dynamic plate resistance. Voltage amplifiers, on the other hand, are loaded with resistors from twice to several times the plate resistance, and this practice gives better results for voltage amplification.

PENTODE POWER AMPLIFIER. Pentodes designed for the audio final stage have higher power sensitivity and, therefore, require less exciting voltage. Most receiving type pentodes have power outputs around 4 watts, while triodes average as a class around 2 watts. The signal needed for some pentodes is as little as 12 volts peak, while many triodes need a peak signal of 50 volts. Since pentodes have extremely high plate resistance, they are loaded with impedance values considerable lower than this plate resistance. Usually the value of the load is determined by radio engineers, considering the amount of distortion and power output. A value is selected which will give the maximum power output consistent with permissible distortion. In stages using a single pentode output tube, 10% is considered permissible amount of total distortion.

The type 6F6 power output pentode is often used in radio circuits and we invite you to look up the characteristics of this tube in the charts of Lesson Nine. You will notice that the power output increases from 3 to 5 watts (1,000 milliwatts equals one watt) as the plate supply voltage is increased from 250 to 315 volts. When the screen grid is tied to the plate, the tube becomes an ordinary triode, having much lower amplification factor and lower power output. The use of two tubes together in special circuits will be discussed later. Please also refer to the socket connections, 7-S, for this tube. Study the connections. Observe that the control grid is terminal number 5. Terminal 6 is not used and could be employed as a support-lug.

Pentodes have greater amplification for the higher frequencies and a small by-pass condenser, to neutralize this effect, is connected from plate to ground. Since the screen grid may be considered at ground potential as far as the audio frequencies, the by-pass condenser, we described, may be connected between the plate and screen grid. The screen grid, of course, is at a high D.C. potential

in respect to ground. This by-pass condenser may be about .006 mfd. rated at 600 volts.

BEAM POWER AMPLIFIER. When a beam power output tube is used in the final audio stage, it acts very much like a pentode. However, less filtering of the power supply is needed. In some circuits, the plate supply is taken right off the rectifier with but a single filter condenser doing the filtering up to that point. The screen grid voltage, however, must be better filtered and is usually of a lower potential than the plate. Check the operating details of a 6L6 tube, used as a single-ended final amplifier.

TUBES OPERATING IN PARALLEL. In order to obtain greater power, two or more power amplifier tubes may be connected in parallel. When two tubes are connected in parallel, the plates are tied together and the other elements are also correspondingly connected together. In such instance, twice the amount of power obtainable from a single tube can be secured from the stage consisting of two tubes connected in parallel. The plate resistance of the combination will be one-half the plate resistance of a single tube. No special advantage* is obtainable from this operation.

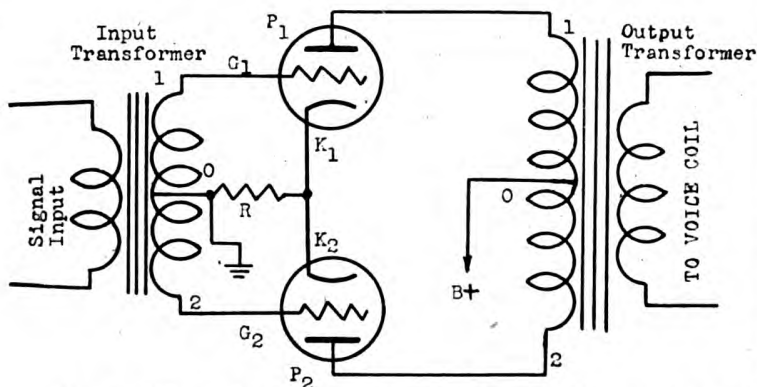


Figure 162. A basic push-pull audio circuit. The operation and advantages of this circuit are explained in this chapter.

ADVANTAGES OF PUSH-PULL OPERATION. Two identical power amplifier tubes may be connected in a special circuit to deliver more than twice the amount of power available from a single tube and at the same time offer other advantages. Please examine the transformer coupled push-pull stage as illustrated. Two similar type of power amplifier tubes are employed and only the cathodes are joined together. The plate current from both of these tubes must pass through the cathode resistor R, in order to reach ground which is the negative terminal of the plate power supply. Therefore, the voltage will be developed across R, and since the grids of both tubes are connected through the windings of the input transformer to the ground, bias will be obtained.

Please notice that the terminal marked B+ is connected to the positive side of the plate power supply. In a push-pull stage, the plate supply need not be filtered very well since the A.C. ripple present will pass to both tubes, traveling through the primary of the output transformer. The winding of this transformer is con-

*Tubes operated in parallel increase the power handling ability in proportion to the number used and also lower the equivalent plate resistance of the combination. In some transmitters, this latter fact is of an advantage.

PUSH-PULL AND PARALLEL

In such circuits, since the screen grid of the power tube and all other stages take but little current, a 3,000 ohm resistor is used instead of a filter choke:

Some electronic circuits require very low plate resistance, r_p , and this can be achieved by connecting several tubes in parallel.

A push-pull stage need not be self-biased. Other biasing methods, as in the case of *single-ended* tubes, may be used instead.

By identical tubes, we mean the same types and also matched to each other so that their characteristic curves are almost exactly the same.

ADVANTAGES OF PUSH-PULL

The grids have equal and opposite polarity changes as compared with the ground potential.

We assume that the tubes are operated over the straight portion of their characteristic curves. This is true to a large degree in a practical case.

Reference is made to the output transformer which couples the tubes to the speaker. This transformer is known as a push-pull output type.

The recommended load for pentode push-pull tubes may be very much different than twice the load for a single tube.

As compared to the voltage at the center tap, the voltages at the two end terminals of a push-pull input transformer are 180° out of phase with this tap.

tinuous and the current, in going to the two tubes, will travel in opposite directions from the center. Therefore, the magnetic fields, set up in each half of the winding because of the ripple, will be opposing and the ripple will not re-appear in the output of the voice coil. The first advantage of a push-pull stage, as you can see, is less filtering needed in the power supply.

Referring now to the input transformer, please observe that an input signal produces a voltage across the entire secondary winding. If we consider center point, marked O, as neutral, then when point number 1 becomes positive, point number 2 is of exactly the same voltage, but correspondingly negative. Therefore, the two grids, marked G-1 and G-2, have equal but opposite polarity voltages at all times.

Since the grids will always have equal and opposite polarity voltages, the current while decreasing in one is correspondingly increasing in the other tube. For example, if these tubes are of such type as to have 40 ma. plate current per tube with no signal; the instant the plate current of one tube increases to 55 ma., the current in the second tube will correspondingly decrease to 25 ma. Since the plate currents of both tubes must pass through the biasing resistor R, and since, as you can see, the current for both tubes when added together will always equal a constant quantity (80 ma. in this case), the voltage drop across the resistor, R, will also be constant as required. Also because this voltage drop will not follow the audio variations, as the case of a single ended amplifier, no cathode by-pass condenser is needed. This is an important economy feature.

The varying currents from the two tubes, representing the signal, are added in the primary of the transformer, and a corresponding voltage is induced in the secondary which is connected to the voice coil. Since the magnetic fields produced by the D.C. currents are opposite in the two halves of the output transformer primary, no magnetic saturation can result and a lower priced output transformer will give as good results as a larger, more expensive transformer when it is used with a single tube. The push-pull action eliminates even order harmonics to a large extent and, therefore, with the same amount of permissible distortion, the vacuum tubes may be operated over a wider portion of their characteristic curves and deliver more than twice the rated power output of a single tube.

Besides triodes, pentodes and beam power tubes may be used in push-pull operation. The output transformer must be obtained to match the plate-to-plate impedance, and the required values are given in tube charts.

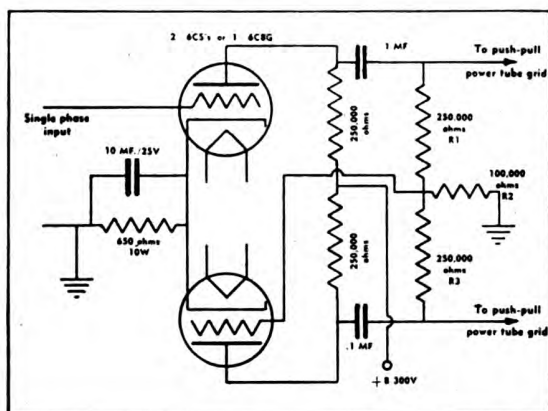
PHASE INVERTER. You have already learned that the two tubes used in a push-pull stage must have the signals 180° out of phase. In transformer coupled circuits, the proper phase is obtained automatically with the connections used. However, transformer circuits do not give as good quality as resistance-coupled circuits, and good quality transformers are expensive.

If a signal available in the pre-amplifier, used to drive a push-pull stage, is of a single phase only, some method is needed for inverting (shifting 180°) the signal for one of the tubes used in the push-pull stage.

The phase inverter circuit employs two triodes or a single tube containing two triode sections. One of these triodes is simply an amplifier, while the second adds nothing to the gain but does re-

verse the phase 180° . The circuit of a phase inverter is illustrated.

Please observe that a single-phase input is fed to one of the triodes. The output of this tube represents an amplified signal 180° out of phase with the original input signal. This output goes to the control grid of one of the push-pull tubes. But besides this, a small portion of the voltage of this signal is re-impressed on the grid of the second triode tube used in the phase inverter. Only that fraction of the total amplified signal is fed to the grid of the lower phase inverter tube, which will make the signal to this tube exactly equal to the original signal at the input to the inverter stage. Bear in mind, however, that this signal to the second tube is 180° out of phase with the original.



Courtesy Allied Radio Corp.

Figure 163. A self-adjusting phase inversion circuit employed for the purpose of driving the push-pull stage from a source of single-phase signal.

This second tube of the phase inverter also reverses the phase (places it again 180° out of phase), and the signals delivered to the two grids of the push-pull stage are 180° out of phase.

Although a 10 mfd. by-pass condenser is used across the cathode resistor, it is not really needed. The currents through the two tubes of the phase inverter are always increasing and decreasing exactly opposite to each other and their total is a constant. Therefore, as in the case of a push-pull stage, no audio variations appear across the cathode resistor and no by-pass condenser is required.

The fraction of the signal from the first inverter tube, which is fed to the second tube, is automatically made to be of the correct value. If this signal is too large, the output from the second phase inverter tube will also be large. This output signal produces a voltage drop across R-2, out of phase with the original voltage which comes from the tube in the upper section of the circuit. It will, therefore, reduce this signal until it is of the correct value.

CLASS B AMPLIFIER. Certain tubes such as type 46, pass very little current without the presence of a signal. Other tubes may be biased negatively to a point where the plate current will be zero. Let us assume two such biased tubes are connected in a push-pull circuit. We will learn that the circuit will not behave as a push-pull arrangement. You must also understand that tubes cannot be biased to cut off (zero plate current) with a cathode resistor. With

PHASE INVERTER CIRCUIT

You have already learned that an amplifier tube inverts the phase of the signal by 180 degrees.

Read this paragraph again and fix the idea clearly in your mind.

Trace this through in the circuit.

This is a special feature of this particular phase inverter circuit.

Class B operated tubes are used for high audio power requirements and for certain stages of radio transmitters.

CLASS B AND A' OPERATION

While the usual interstage transformer does not handle any real power, the transformer driving a *Class B* stage does handle power on signal peaks.

The *Class B* power output stage using (for example) type 59 tubes connected as triodes, has a current drain of 26 ma. with no signal, and a possible peak plate current of 200 ma. This certainly is considerable variation.

Headphones are still used extensively in communications work. The understanding of the principles which permit the operation of headphones will help you follow the explanation about loud-speakers.

no plate current, there will be no voltage drop in the resistor. Separate bias supply must be used.

The figure of a push-pull circuit, a few pages back, will help you follow the explanation. When a signal is present, during the first instant one of the grids is receiving a positive signal voltage, while the grid of the other tube receives a negative signal voltage. The grids are already biased to cut off and, if a grid is driven more negative, the plate current will still remain at zero. However, a positive voltage will reduce the cut off bias and plate current will be present. The amount of plate current through the tube will depend on the strength of the signal. Please notice that only one tube is conducting at a time. As the voltage on the two grids reverses, the other tube will conduct, but the one with the negative voltage will have no plate current present.

The action suggests a *push-push* arrangement; one tube "pushes" at a time. Since at times the grids are driven positive, the preceding stage must be capable of supplying the power drawn by the grids under this condition. This is accomplished by using for a driver stage a *Class A* power amplifier of suitable size, coupled by a transformer possessing the proper characteristics. The transformer is usually of a step down type.

With *Class B* it is possible to obtain high power output with comparatively small tubes operating at ordinary plate potentials. Since very little power is consumed with no signal, economy is another advantage. To offset these, the distortion present is always somewhat larger than for class A operation and the power supply must have very good regulations to maintain proper operating voltage with considerable current variations.

CLASS A'. It is possible to operate a power amplifier stage intermediary between *Class A* and *Class B*. This type of operation is called *Class A prime*, or *A'*. The bias used is greater than for the same tubes in *Class A*, but not enough to cause cut off. On low signals, the circuit behaves as a *Class A*, while on powerful signals the *Class B* action allows the handling of large power.



Figure 164. Head phones are employed to convert electrical energy at audio frequencies to corresponding acoustical (sound) energy.

Courtesy Trimm Mfg. Co.

HEADPHONES. Telephone headphones are used to convert electrical energy of suitable intensity back to sound energy. A diaphragm of magnetic material is placed close to one or two electromagnets. These electromagnets are usually connected in series and their resistance is of the order of 1,000 or 2,000 ohms. A fixed magnet is also included in the assembly and acts upon the diaphragm. Because of the fixed magnet, the diaphragm is always attracted inwards, but as the electromagnets become magnetized with the A.C. corresponding to the sound received, the magnetic fields add to and subtract from the existing field of the fixed magnet. This makes the total magnetic strength increase and decrease in accordance with the current variations. As you can see, the

vibration of the diaphragm is a function of the current which in turn is the electrical equivalent of the sound. If the permanent magnet was missing, the diaphragm would be attracted twice for each cycle (both on the positive and negative peaks) and the reproduction would not be true.

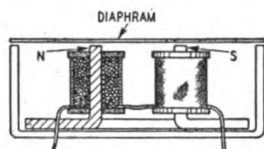


Figure 165.* The inside view of a headphone showing the position of the electro-magnets and the permanent magnet.

MAGNETIC LOUDSPEAKER. This type of loudspeaker, no longer popular, operates on the principle of the headphone. Instead of the diaphragm, a vibrating reed is used and is connected mechanically to a light cardboard cone. As the electromagnets are excited with the audio currents, the cone will vibrate and produce audio sounds. The fixed magnet is much larger in the loudspeaker and the impedance of the electromagnets is made to match the value required for the equipment used. These speakers are not recommended for reproducing power greater than three watts.

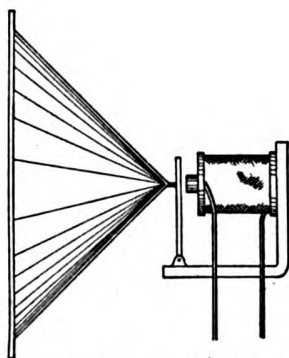


Figure 166. A detailed illustration of a magnetic speaker. These speakers are no longer popular.

BAFFLE REQUIREMENTS. The speakers must always be used with some form of baffle to prevent the tendency of the front and rear sound waves from cancelling-out each other. If the baffle were omitted, sound compression produced in front of the speaker cone, when the cone moves forward, would cause the air to rush around the edges and relieve the rarefaction in the rear. To be equally effective to the middle and lower frequencies a baffle must be fairly large. In practice a 6" of 8" speaker will require a baffle with 40 inch sides.

A speaker mounted in a flat baffle made by ply-wood, celotex, or masonite will radiate sound almost uniformly in all directions.

*Figure 165 above, and also Figures 166, 167, and 171, are published through the courtesy of P. R. Mallory & Co.

ELECTRO-ACOUSTIC DEVICES

The magnetic field is present at all times. It is increased and decreased with the current passing through the electromagnet.

The vibration of a body (cone) in air produces audio sounds of the frequency of the vibration.

The usual radio cabinet serves as a suitable baffle. However, the smaller cabinets have a tendency to stress certain frequencies to which the cabinets may be resonant.

DYNAMIC LOUDSPEAKERS

The voice coil of the cone may be centered around the pole piece and kept in position by the cone itself which is glued around its outside rim to the metal frame work of the speaker. The cone may also have center flexible ribs attached to the voice coil and supporting the assembly at this point to the metal frame.

This cross-sectional view does not show mechanical supports for the cone assembly.

Output tubes may require a load of several thousands ohms which must be matched to the voice coil impedance of several ohms.

Speakers possessing fair response characteristics have been made with a three inch diameter cone.

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If the installation requires the projection of the sound forward, directional flares or special horn baffles must be employed.

DYNAMIC SPEAKER. The most popular loudspeakers in use are of the electrodynamic types. These speakers have the cones made in various sizes from 3 to 14 inches. The cone has a small coil mounted at the center. The coil-form rides over a pole piece of magnetic material, but does not touch this cylindrical piece. The coil itself is made of several turns of copper wire (about No. 20), having a D.C. resistance, in many speakers, of 6 ohms, and the A.C. impedance, to audio frequencies at about 400 cycles, of 8 ohms. The pole piece, we mentioned, passes through the center of a large electro-magnet. This electromagnet is called the field coil and in an average loudspeaker consumes about 5 watts of power. The D.C. resistance of the field may vary and is designed to match the circuit. Usually this value of field resistance is between 800 and 3,000 ohms. The field, in radio receivers, must be energized from a source of D.C. voltage and may be used as the filter choke. The usual loss of energy in the filter choke, therefore, is utilized for the required magnetic field and further the cost of the choke is saved since it will not be needed.

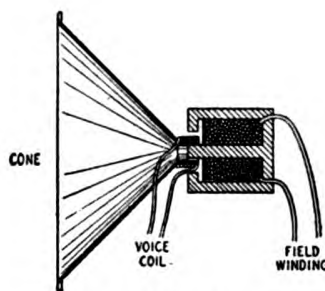


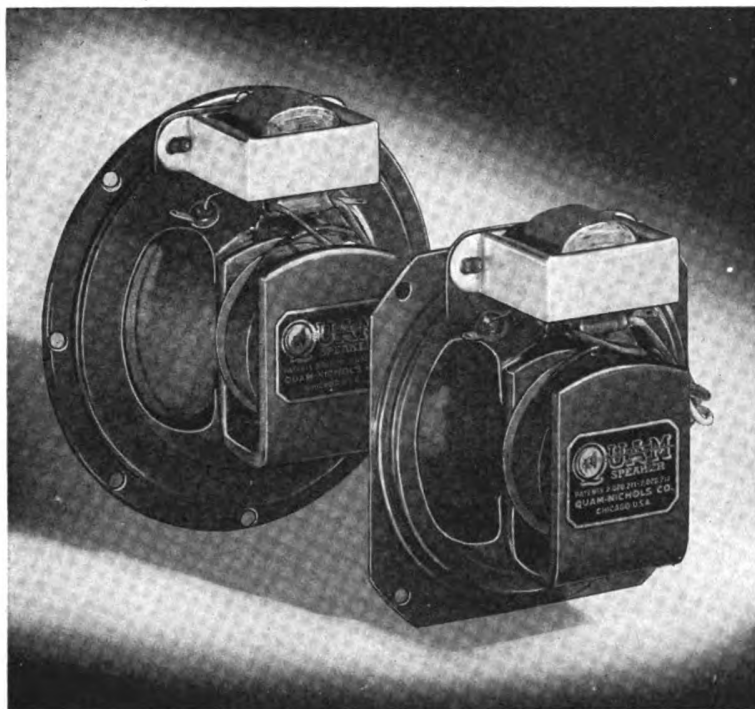
Figure 167. Cross-sectional view of a dynamic speaker showing the position of the voice coil and the field winding.

In operation, the dynamic speaker is so connected that the field winding is magnetized. The voice coil, being of very low impedance, is properly matched to the output stage of the radio or amplifier with the aid of an output transformer. As the voice coil receives alternating current which corresponds to the sound to be reproduced, the coil sets up its own magnetic field which may oppose or be attracted by the field of the larger electromagnet (field coil) of the loudspeaker. Since the voice coil is fastened to the cone, the cone will move (vibrate) in accordance with the current entering the voice coil. This action, as in the case of magnetic speaker, will produce sound. At low frequencies, the cone acts as a piston of a cylinder, moving up and back at the audio frequency rate. At high audio frequencies, the cone vibrates.

The smaller dynamic speakers, under 8 inches, can successfully reproduce up to about 3 watts of audio power. Some of the larger 12 inch speakers, used especially for serving large groups of people with sound, can handle up to 15 watts of power.

Care must be exercised in using speakers not to puncture a hole in the cone. The tone quality of the speaker will be ruined if a

break develops in the cone. The cone may be replaced and replacement units are available on the market. Care must be used in mounting the replacement; the voice coil must not touch any part of the pole piece.



Courtesy Quam-Nichols Co.

Figure 168. Commercial dynamic speakers are available with cones of various sizes. Most speakers, as the models illustrated, have the output matching transformer mounted on the speaker frame.

P.M. SPEAKERS. The development of very powerful fixed magnets, has permitted the replacement of the electro-magnetic field with a small permanent magnet. In all respects, permanent magnet (P.M.) speakers operate exactly as dynamics, but the field coil is omitted. Certain manufacturers, in fact, have similar models available in either dynamic or P.M. types.

IMPEDANCE MATCHING. To transfer maximum power from one electrical unit to another, the impedances of the units must be the same. This is possible in many cases and equipment is designed with this in view. But many other times, the equipment, which must be connected together, cannot be made with equal impedances. We have an example of this with the power output tube, and the loudspeaker. An output type tube may require 3,600 ohm load for maximum power output and least distortion. But the best speaker to use may be of the dynamic type which has a light weight voice coil of a few turns of wire. Only a small impedance can be obtained from a few turns of wire. We have already mentioned that 8 ohms impedance was common for a voice coil. How can these two units be used together and not produce a bad mismatch?

A transformer comes to our rescue. It is possible to connect widely different impedances to the two windings of a matching

SPEAKER IMPEDANCE MATCHING

Sometimes, a complete replacement speaker may cost but a few pennies more than the separate cone needed for the repair.

In handling unmounted loudspeakers or radio chassis with exposed speakers, be careful not to puncture the cone of the speaker. For safety sake, a heavy piece of cardboard may be cut to the size of the cone and attached with two machine bolts to the front of the speaker.



A 12" dynamic speaker used for sound installation work.

Magnetic loudspeakers may be made to match directly the output tubes.

OUTPUT TRANSFORMER

For example, if the turns ratio is 3 to 1, the impedance ratio will be 9 to 1.

A matching transformer must be used for the purpose intended with both the primary and secondary connected to proper values, otherwise the expected action will not be obtained.

Transformers of this type also permit the connection of several loudspeakers to a single radio receiver or amplifier. With relatively simple circuits, it is possible to correctly match all impedances and deliver *different* amounts of audio power to the several speakers used.

These new values of impedances should not vary more than 50% from the design values if distortion is to be avoided.

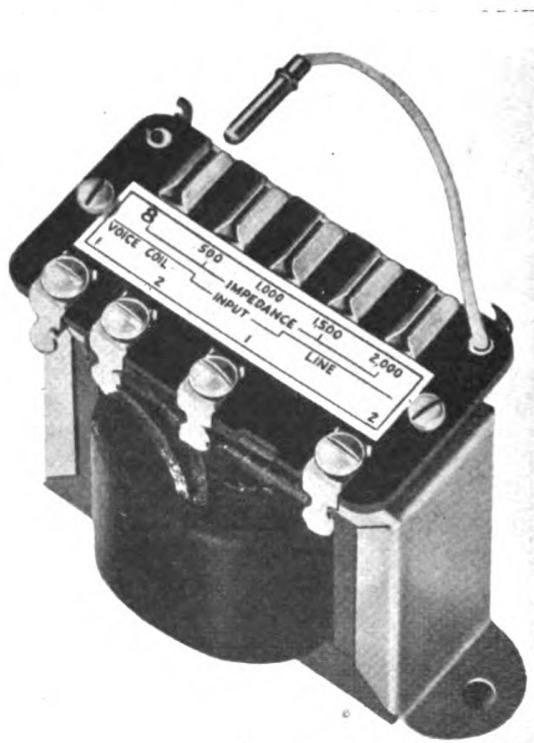
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transformer! By making the turns ratio of the primary to secondary correct, each impedance "will see" a value corresponding to itself. The turns ratio, which must be used, is equal to the square root of the impedance ratio. Letting N_p represent the turns of the primary, N_s for the secondary, and Z_p the impedance of the primary, Z_s impedance of the secondary, we have an important formula:

$$\text{Turns Ratio} = \frac{N_s}{N_p} = \sqrt{\frac{Z_s}{Z_p}}$$

In our example of the previous paragraph, we had a voice coil of 8 ohms, and it is connected to the secondary, that is Z_s must represent an impedance of this value. Please understand that Z_s will appear to the voice coil as an 8 ohms impedance only if the primary is correctly connected also. The actual secondary coil does not necessarily have 8 ohms impedance. The primary must be used for the load of the tube which requires 3,600 ohms. Then Z_p must appear as 3,600 to the tube; here again the actual impedance of the primary coil is nothing like the impedance it is to represent. Let us use our formula to find the turns ratio of the transformer.

$$\sqrt{\frac{Z_s}{Z_p}} = \sqrt{\frac{8}{3600}} = \sqrt{\frac{1}{450}} = \frac{1}{21.2} = .0472$$



Courtesy Jensen Radio Mfg. Co.

Figure 169. Universal line-matching transformers are employed to match audio transmission lines of different values of impedance to the voice coil of a loudspeaker.

Most transformers employed for matching impedances are rated in actual impedance values. But by knowing the formula, you may calculate many other values of impedances for which the same transformer will be suitable.

EFFECT OF MISMATCHING. A great deal of stress has been placed on the necessity of exact matching from source to load. While this generally holds true when the mismatching is considerable, a slight mismatch is not serious, as can be seen as shown by the chart.

In order to properly determine correct matching, the impedance of the voice coil must be known. This impedance is not a constant figure, but varies with frequency. For all general applications, however, the impedance is measured at 400 cycles. In the event that the impedance of a speaker is not known, the approximate value can be obtained by multiplying the D.C. resistance by a factor of 1.25.

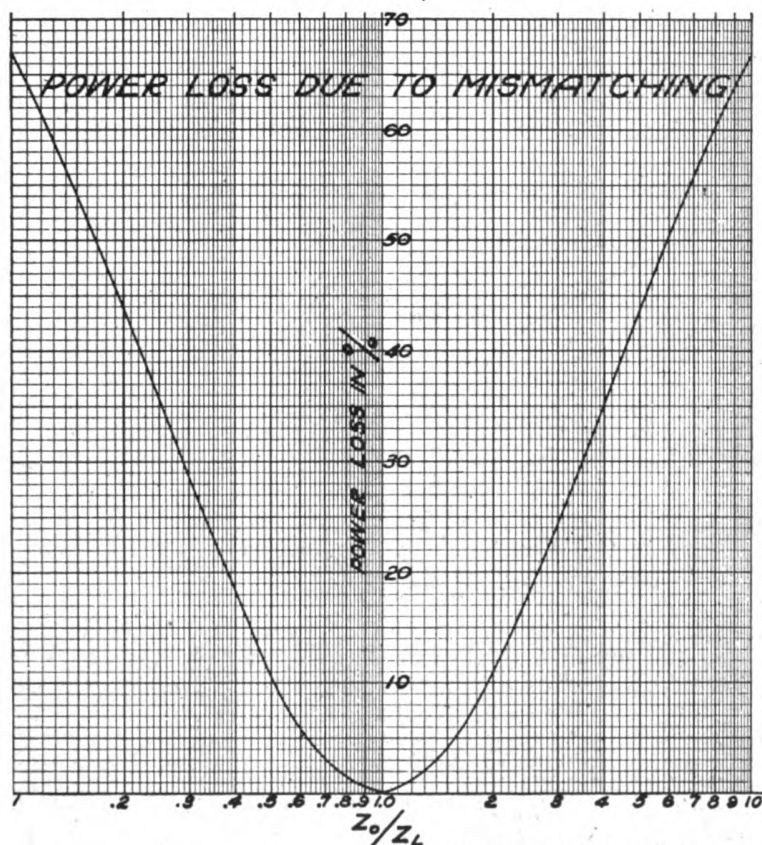


Figure 170. You can tell the amount of audio power lost because of mismatching, by using this graph. An explanation how to use this graph is given in the text.

To consider the usefulness of the graph, let us take the problem where the only speaker available is one with a 6 ohm voice coil, and the amplifier output is available as either a 4 ohms or 8 ohms. The question in this case is what tap on the amplifier will give the

best results. The ratio of $\frac{Z_{\text{output}}}{Z_{\text{load}}}$ in the case of the 4 ohms output is .666, and in the case of the 8 ohms output is 1.33. In checking these figures on the graph, we find that in the case of 4 ohms where the ratio is .666, the loss is approximately 4%, and similarly, on the 8 ohms, the loss is only 2½%. It is quite obvious that the best results will be obtained if the speaker is connected to the 8 ohms. Generally, the results are better if the speaker is mismatched to a higher rather than a lower impedance.

LOSSES DUE TO MISMATCHING

For example, if the measured D.C. resistance of a voice coil is 6 ohms; the impedance is 6×1.25 , or 7½ ohms.

Besides the power loss encountered because of mismatching, distortion also will be introduced in case of a mismatch. If the output stage uses a triode vacuum tube, less distortion will be present if the mismatch is due to the load impedance being too high as compared to the load being correspondingly too small.

4 ohm output, 6 ohm load, in one case; and 8 ohm output, 6 ohm load in the second case.

INVERSE FEEDBACK CIRCUIT

The change of the tube characteristics with age has little effect on the operation of the equipment if degeneration of a sufficient degree is employed. This fact is very important in telephone repeater amplifiers.

However, if the speaker has only a 2 ohm voice coil, and the only output available on the amplifier is 8 ohms, the ratio of the two impedances is 4. From observation on the graph, the loss is 35%, which is quite serious and this mismatching is not recommended.

INVERSE FEEDBACK. The student will be told a little about audio degeneration or inverse feedback. This action is obtained by making minor changes in audio circuits and gives certain advantages. The results of degeneration* may be summarized as follows:

1. Power output remains more constant.
2. Audio distortion is decreased.
3. Frequency response is improved.
4. Signal voltage must be larger.

Audio degeneration is obtained by feeding part of the output signal back, in proper relationship, to be exactly out of phase. The feedback path may be such as to include several tubes in the circuit, but is usually confined to one or two tubes.

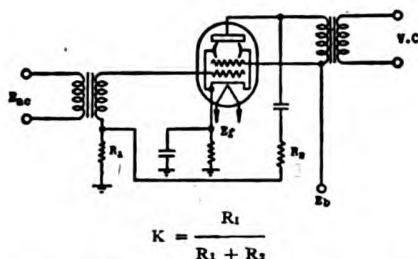


Figure 171. A simple degenerative circuit which can be understood by analyzing the action of the feedback voltage supplied through resistors R_1 and R_2 .

Let us consider a simple feedback circuit. In the figure, we have a beam power output tube. It is excited by a signal, marked E_{ac} in the drawing, and is a basic circuit except for R_1 , R_2 and the coupling condenser. For the moment, we will study the regular function of this circuit. The input signal is induced in the secondary of the interstage audio transformer and excites the control grid of the tube. The resistor R_1 , is small and need not be considered for the moment. The tube is self biased with the resistor in the cathode circuit. This resistor is by-passed with a large capacity (about 20 mfd.) electrolytic condenser which is not marked in the drawing. The screen grid of the tube receives the plate voltage directly; terminal E_b . The plate current for the tube is supplied through the primary of the output transformer. This transformer matches the tube to the voice coil. The required size of this transformer, by the way, will be different with degeneration, in the case of most vacuum tubes.

Now let us consider the additional circuit which produces degeneration. Trace this circuit from the plate of the tube, through the blocking condenser, and through the two resistor R_1 and R_2 . The blocking condenser, we mentioned, is used only to keep D.C. of the plate supply out of the resistor network. This condenser may be considered as having zero impedance to the audio signals. You can see that the audio signals coming out of the tube, divide them-

This means that with degeneration, the output tube will have different characteristics.

*See the footnote reference on page 61.

selves across the two resistors. The amount of signal across R_1 , in terms of the total available signal at the plate, will be a factor K , equal to the simple formula stated under the illustration. Since only a small amount of signal is fed back, K will be much less than 1.

INVERSE FEEDBACK ACTION

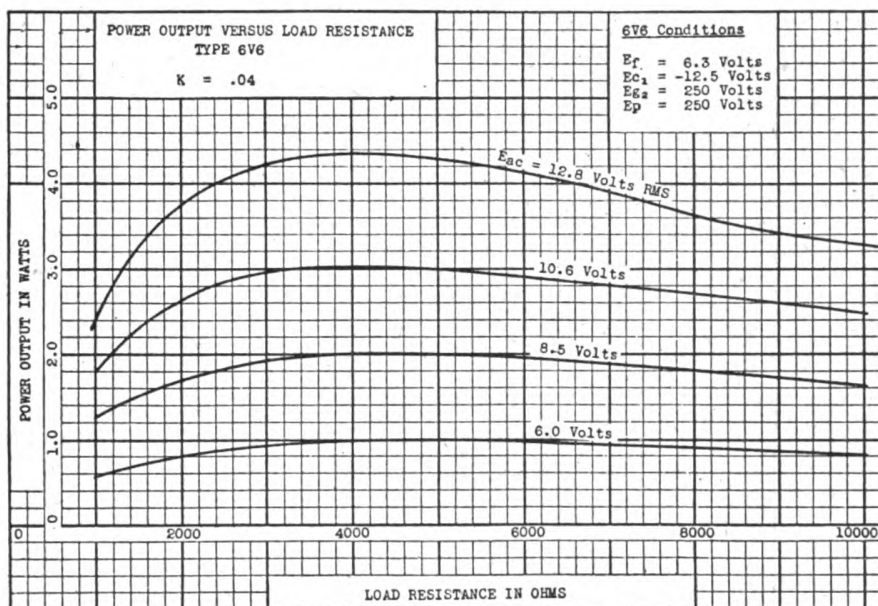


Figure 172. The power output of a radio tube varies less with changing load resistance if inverse feedback is employed. The curves show the results with different excitation voltages.

Another way to analyze this action is to realize that if R_2 is large, and R_1 is small, little voltage will develop across the smaller resistor. By changing the size of these resistors, the voltage across R_1 may be made any value required in terms of the total voltage available at the plate of the tube. Notice that the voltage across R_1 adds in series with any voltage induced across the secondary of the input transformer, and both of these voltages are impressed on the control grid.

Now, it is a well known fact that a vacuum tube shifts the phase of the signal 180° . When the grid is becoming more positive, the plate current is increased, the impedance of the load causes a larger voltage drop, and less of the total battery voltage is left for the tube. This means that while the signal is becoming more positive, the voltage fed back by the degenerative system is negative in relationship. When signal is either positive or negative, the voltage fed back is just the opposite. This is degeneration and produces the effects we described.

Another negative feedback circuit is shown and this type of circuit is well suited for use with resistance coupled stages. Please notice that only R_2 and the blocking condenser form the degenerative system. The action is very similar to the one described. Many commercial circuits not having audio degeneration, can be converted to include this feature by the simple addition of this condenser and resistor. The condenser may be .01 mfd., 600 volt type, the resistor should be about 5 megohms. However, bear in mind that the same transformer will no longer correctly match the

With inverse feedback, the power output changes less with variations in load impedance than would be the case without degeneration.

The understanding of inverse feedback has its difficult points. Please reread this section until the function of the degeneration circuit of Figure 171, is clear to you.

You are safe in trying this addition on any suitable radio receiver.

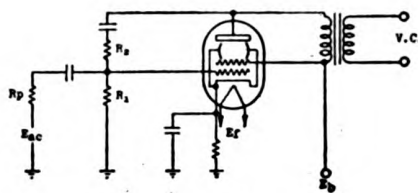
FILTER NETWORKS

Degeneration may be used with beam power tubes as illustrated or with any other types of power output tubes (triodes, pentodes).

Please observe that R_p in a practical circuit will be the plate resistor of the previous stage.

The subject of filter design is quite complex, but a practical radio serviceman will only be required to replace components in a filter network and to have the general knowledge of the theory to make needed tests.

tube to the voice coil and may nullify the advantages of the feedback circuit.



$$K = \frac{RT}{RT + R_2}$$

Where RT = Parallel Resistance of R_p and R_1

$$K = \frac{R_1 R_p}{R_1 R_p + R_1 R_2 + R_2 R_p}$$

Figure 173. Another inverse feedback circuit which can be added to almost any radio set.

FILTERS. Filters are devices which discriminate against certain frequencies. A filter will create larger losses for one group of frequencies than for another. Even a simple condenser placed across a circuit will act as a filter. This condenser will by-pass the high frequencies and have little effect on lower frequencies. By combining capacitors and inductors in suitable circuits, any desired filtering action can be obtained. For best results, the resistance present should be a minimum.

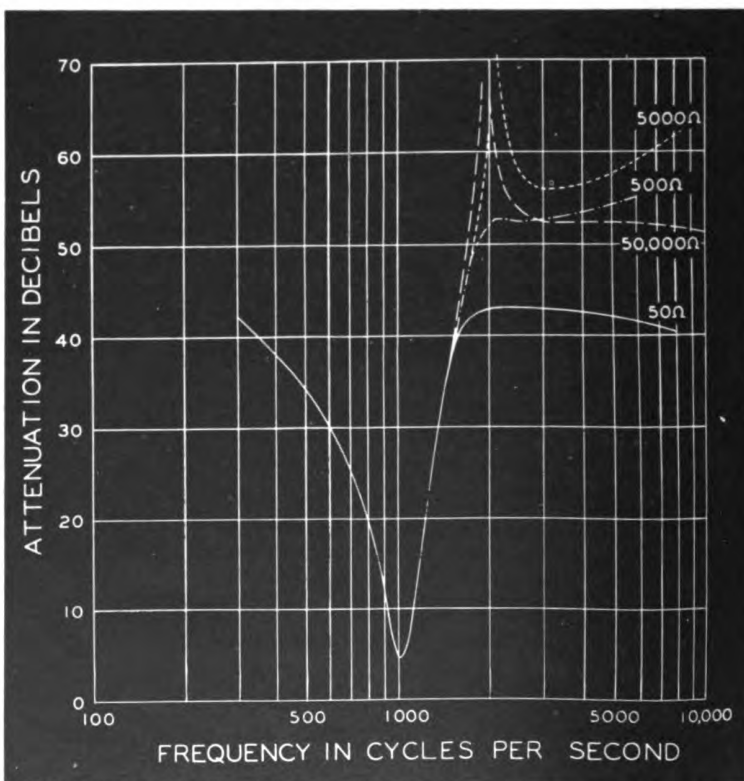


Figure 174. The attenuation or loss in decibels of a special filter designed to suppress all frequencies except those near 1,000 cycles.

FUNCTION OF FILTERS

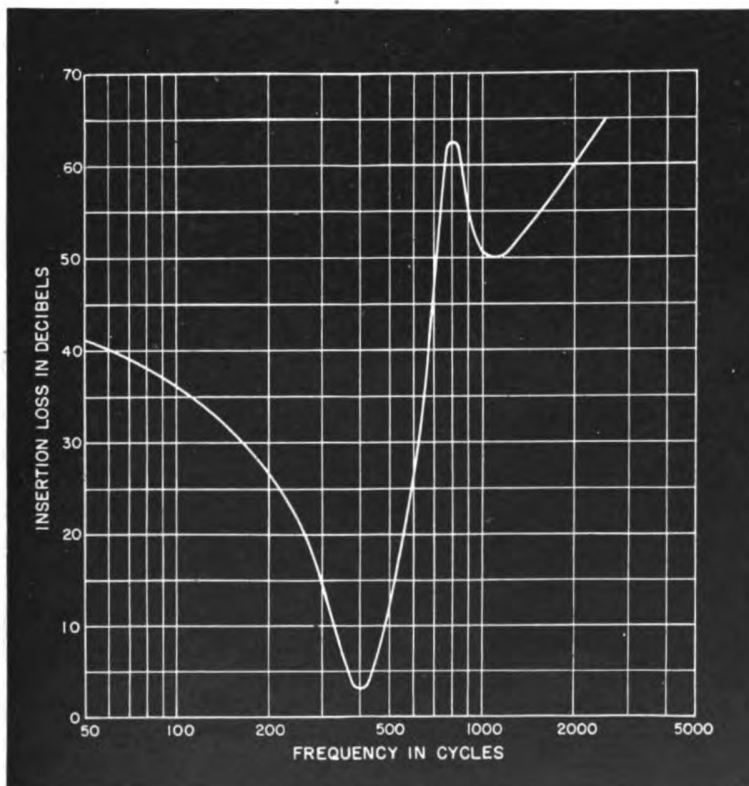
Filters may be designed for all frequencies. When only a band of frequencies is passed by the filter and all other frequencies are suppressed, the filter is called *band-pass* type. If, on the other hand, all frequencies are passed, but just one band of frequencies is suppressed, the filter is a *band-elimination* type. If all frequencies above a certain value are cut-off (eliminated), while frequencies below this cut-off point are passed with almost no attenuation (suppression), the filter is a *low-pass* type.

Audio frequencies are usually plotted on the horizontal scales of graphs, and the scale is made logarithmic. You will notice that there is the same amount of space between 100 and 1,000 cycles, as between 1,000 and 10,000 cycles. The next scale, if included, would have used the same space for frequencies from 10,000 to 100,000 cycles. The vertical scale represents attenuation in decibels (loss). The purpose of this filter, which has its response curve reproduced, is to eliminate (attenuate) all frequencies other than 1,000 cycles. Notice that the attenuation is small for 1,000 cycles, and greatly increases for all other frequencies. The dotted lines show the effect when this filter is not properly terminated, i. e., not loaded with the correct impedance of 50 ohms.

The second curve is also for a band-pass filter. Notice that this filter is designed to pass 400 cycles. The filter has an increased attenuation at 800 cycles for a special reason. Many times equipment producing one frequency which is needed, also has present the second harmonic of this frequency. For example, a 60 cycle

Power supply filter is called *brute-force* type. This filter tries to suppress all frequencies (variations) and pass only direct current.

The divisions between 100 and 1,000 (for example) are also logarithmic. This sub-division is of the same type as used on slide rules.



Courtesy General Radio Co.

Figure 175. Another response curve of a filter designed to pass 400 cycles and to suppress all other frequencies. An especially large loss is introduced at the second harmonic of 800 cycles.

Bear in mind that an insertion loss of 60 decibels corresponds to a voltage reduction in the ratio of one thousand to one. If both 400 and 800 cycles existed as equal voltages, say equal to one volt at the input to the filter, then the output at 400 cycles would be reduced but slightly, but the output at 800 cycles would be reduced to about 1/1,000 of a volt.

PUBLIC ADDRESS SYSTEMS

The input may be a microphone for voice or music, a phono pickup for record reproduction, a radio tuner, a photo-cell excited by a sound-on-film track, or a magnetic recording on a steel tape.

If the microphone cable is broken and joined at some point, the shielding must cover the junction. Shielded plugs may be used for this same purpose.

Catalog material on amplifiers and public address systems will help you learn about commercial units.

This amplifier is designed to supply low power and can be constructed economically.

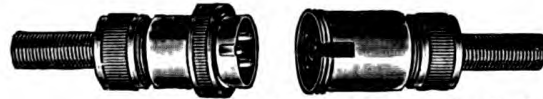
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generator may have a considerable amount of 120 cycle voltage present in the output. Here, the second harmonic of 400 cycles is 800 cycles, and the filter is especially efficient in suppressing this frequency of the second harmonic.

PUBLIC ADDRESS. When a large group of people is to be served with a common program, public address equipment finds its application. Most often a speaker's voice is amplified to a suitable volume to make him audible to all present. Radio programs and phonograph records also serve as a means of the input. If the program originates some distance from the amplifier, a line is used to connect it to the input. In sound moving picture work, a photo-cell serves as a means of input and requires a special amplifier.

Essentially a P.A. system consists of one or more of the sources of input mentioned, the amplifier or any pre-amplifiers necessary, and the output in the form of one or more loudspeakers so placed as to take the greatest advantage of the acoustics.

We have already discussed the different sources of input, the voltage and power amplifiers which make up the P.A. amplifier unit, and the function of loudspeakers. It is essential, however, to consider all these factors together.



Courtesy American Phenolic Corp.

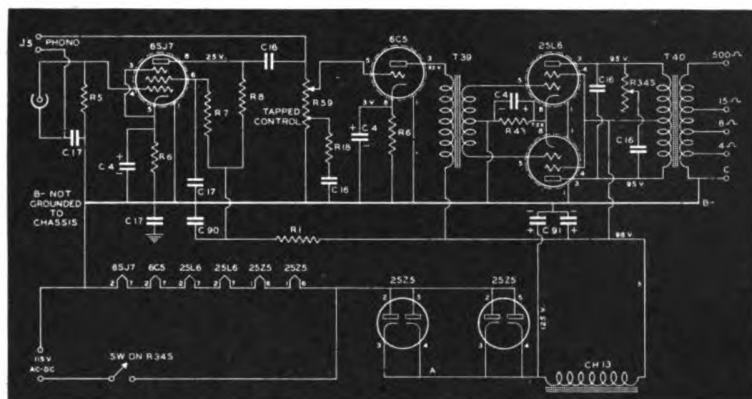
Figure 176. Microphone cables are joined together or connected to the input of an amplifier with a shielded metal connector.

Today, most public address systems use crystal or velocity microphones. These are connected to the amplifier input terminals with rubber covered shielded cable. Ordinarily, this cable has but one central conductor and the shield serves as the return. If the microphone is of the high impedance type, it is coupled directly to a grid of an input stage. In such cases, the microphone cable should be shorter than 100 feet. Low impedance microphones may be used with longer cables, but require an impedance matching transformer at the input to the amplifier. Since microphone circuits are very sensitive and will pick up stray electrical interference, the shielding must be continuous. At the microphone and the input to the amplifier, special shielded type plugs are used.

The output of the microphones used is quite low and most amplifiers employ three stages of voltage amplification and one stage of power amplification. Phonograph-pickup input is coupled to the second stage (eliminating the gain of the first tube) since the output from a phone pickup is much higher than that obtained from a microphone.

The circuit of an amplifier illustrated is a little different. Here we have but two voltage amplification stages, and the power amplifier is of the push-pull type. Total gain of this amplifier is employed for the microphone input. The shield of the microphone cable is grounded to the chassis. Condenser C-17 insulates the ground from the side of the A.C. line. Resistor R-5, 5 megohms, serves as the grid return in case a crystal microphone is employed. The phono input goes directly to the second stage. Although both inputs may be used at the same time, these cannot be mixed in any special proportions. Both input are controlled with the same

potentiometer, R-59. The tap of this control permits a corrective tone control circuit to be incorporated. At low volume settings, the resistor R-18 and condenser C-16, by pass a great deal of the higher frequencies and the equipment stresses bass. As the volume is increased, the slider of the potentiometer is moved upwards. This adds part of the resistance of the potentiometer to R-18, decreasing the by-pass action of the condenser.



Courtesy Standard Transformer Corp.

Figure 177. Circuit of a small, efficient amplifier. Please observe that the filaments are wired in series and, since the total voltage adds up to about 115 volts, no dropping resistor is needed.

The stage using type 6C5 tube increases the voltage gain. The dotted circle around the tube symbol indicates a metal shield either around the entire tube, or about the sections having the control grid connection.

This voltage amplification stage is transformer coupled to a pair of 25L6 beam power tubes. The transformer places the grids of the two tubes 180° out of phase and permits push-pull operation. There is a tone control in this stage. The output transformer has several taps on the secondary and, thereby, furnishes several commonly used impedances. The socket permits easy connection of the speaker.

The power supply is of a half-wave rectifier type. Two type 25Z5 tubes are employed since the current drain is quite heavy. Notice that the filaments connected in series add up to 112.6 volts and, therefore, no series resistor is needed. The output of this amplifier is rated at 4.5 watts, and the unit is suitable for many applications where a low priced, low power unit is needed.

The larger amplifiers incorporate many refinements. They may have inputs for several microphones and phono pickups, and permit the mixing of these different channels. The circuit may be more refined, incorporating inverse feedback for better results. The power output may be anything from 4 watts to 50 or 100 watts when using receiving type tubes. With transmitting type audio tubes the power may be in thousands of watts.

SPEAKER PLACEMENT.* In all public address installations, loudspeakers are more than just an accessory of the system; they must be considered as the all important devices used to convert the electrical audio output to the needed acoustical energy—sound. The speakers of any well matched sound system are selected with

PUBLIC ADDRESS AMPLIFIER

Actually, the *highs* are killed to a large extent and the bass is left.

The condenser, C-4, is included since at peak signals the tubes in this stage may not be operated in push-pull.

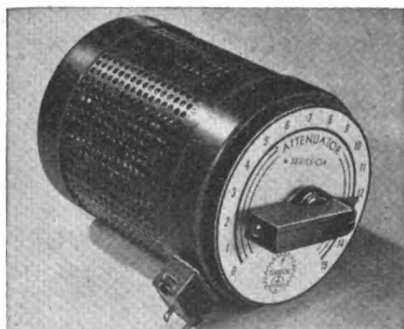
If a load is connected to any one impedance tap, the other taps will no longer offer the impedance values as marked. Terminal C is common for all connections.

If the amplifier is operated from a source of 110 volts, D.C. power, the rectifiers are left in the circuit but then do not serve any useful function.

*Parts of this section are reprinted from "Oxford Techni-Talks" January, 1939, originally prepared by M. N. Beitman for Oxford-Tartak Radio Corp.

LOUDSPEAKER PLACEMENT

Speaker connections are made to a socket which is usually located in the rear of the amplifier. A rotary switch may be incorporated to *select* the proper impedance. In some units, a terminal connecting board is used.



Courtesy Clarostat Mfg. Co.

Figure 179. A constant impedance output attenuator is used to control individual loudspeakers without unbalancing the circuit.

care so that the response characteristics and power handling ability will give the desired results with the associated equipment. But the proper placement of the speakers and the use of correct baffles or directional horns is necessary to permit the P.A. technician to secure the best results from the sound system in any particular installation.



Photograph Courtesy Standard Transformer Corp.

Figure 178. Front-top view of the amplifier described. Notice the input connectors for phonograph and microphone at the left hand side of the chassis. The controls are on the front panel.

In average installations, it is best to use one or two speakers. A single 10 inch dynamic speaker will serve in class rooms, hallways, small stores, and in almost all other installations requiring less than six watts of power. For auditoriums, churches, gymnasiums, dance halls, two speakers of good quality should be able to handle the audio volume from amplifiers supplying 15 to 30 watts. These speakers must have a conservative power handling capacity of at least 15 watts each. For use with amplifiers supplying greater power, employ directional trumpet speakers or at least four well made 12 or 14 inch dynamics.

The speaker location is selected with two objectives in mind: (1) to make the program sound natural to all present, and (2) to reduce the possibility of acoustical feedback. The loudspeakers should be placed so that sound originating from the actual source (be it a singer or a complete orchestra) and the sound emitted by the loudspeakers should reach the majority of the audience at the same instant. This is why two speakers are used in auditoriums and dance halls, one on each side of the stage. This type of installation permits the original sound to be supplemented or reinforced by the amplified output. It certainly would not do to have a single speaker in the back section of a long and narrow hall. Under such a condition, the listeners sitting in the first front rows and those in the extreme rear would hear the original sound and the amplified sound at a considerable time interval.

AUDIO FEEDBACK PROBLEM

SOUND FEEDBACK. In all installations, some of the sound emitted by the loudspeakers will reach the microphone of the system. Feedback will result if the sound reaching the microphone is greater in intensity than the original sound input. Consider, for example, a typical auditorium with an orchestra playing. A definite sound level produced by the instruments of the orchestra is picked up by the microphone. After amplification, a correspondingly higher power level of sound is emitted by the loudspeakers. Of course, the actual ratio of the input to the output power is the net gain of the amplifying equipment at the volume control setting employed. Now if the sound coming back to the microphone, either through direct radiation or by reflection from walls, is about equal in intensity to the original input, twice as much output will result. This larger output will in turn cause twice as much sound energy to be returned to the microphone and again the output level will be doubled. This doubling process will continue, under such condition, at a rate equal to the time required for the sound to pass acoustically from loudspeaker to microphone and electrically through the amplifying equipment. In several seconds, the amplifier will be overloaded, and a continuous loud whistle will be the only output present.

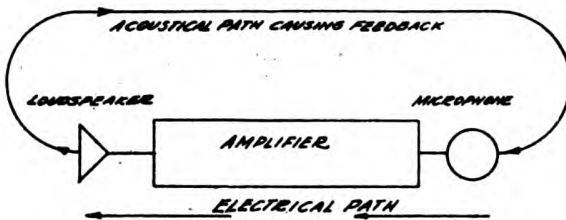


Figure 180. A certain amount of acoustical energy released by the loudspeaker reaches the microphone. If the intensity reaching the microphone is sufficiently large, feedback will result. Methods for eliminating and preventing feedback are described in the text.

Should the sound returning to the microphone be greater in intensity than the original, the feedback action will start just so much faster. If the sound intensity is but a little less than the original input, a hang-over effect or echo will be present. All these conditions are equally bad and can successfully be eliminated.

SOLUTION OF THE FEEDBACK PROBLEM. Reduction of amplification will always solve the feedback problem. But this is a poor solution, since the output in majority of cases must be reduced to so low a point that the sound system no longer serves its purpose. In some installations, certain groups of frequencies are the only cause of feedback. Perhaps this is due to greater amplification at these frequencies or to the resonant effect of the room. Tone control adjusted to reduce the gain at these frequencies, will eliminate the feedback due to this cause. But this, too, is a make-shift solution, for the tone control adjustment not only may solve the feedback problem, but also may distort the natural qualities of the program.

The way to eliminate feedback is to prevent sound from the speakers reaching the microphone of the system. If the speakers are focused in a direction away from the microphone, direct feed-

Read this paragraph with care. Here you will find the explanation for sound feedback. Observe that the complete path of the sound oscillations requires the travel of the sound in the air of the room and the passage of corresponding electrical energy through the amplifying equipment.

If you have a chance to operate a sound system and an opportunity presents itself, try to produce the various degrees of sound feedback as described in the text.

Reduction of the volume level is the immediate solution if the oscillations start while the "show" is going on.

PRACTICAL REVIEW QUESTIONS

Moving the speakers and microphone may reduce the tendency of the system to oscillate.

2. Give several possible reasons due to the acoustics and the amplifier installation.

5. You will have to use the decibel chart.

6. A tenfold increase in power is needed.

7. And what is the voltage ratio? Is this quantity obtainable from a practical circuit?

12. Make a diagram to make your answer clear.

14. Use the formula $X_c = \frac{159,236}{f \times C}$, where the value of C is expressed in microfarads.

19. Notice that a phase (time) difference may exist between voltage and current, or two voltages, and in the same or different circuits.

back will be eliminated. However, sound reflected from walls, ceiling, and floor will reach the microphone. The sound in being reflected, loses some of its energy, so that in striking several walls in its return path to the microphone, the sound intensity may be reduced to a low value where it will no longer create any feedback. Since sound-absorbing materials deaden the sound and absorb its energy, the use of carpets, heavy curtains and drapes, and special sound-absorbing materials strategically placed will permit the use of the public address system at the required volume level without encountering feedback.

REVIEW QUESTIONS AND PROBLEMS. 1. The velocity of sound on a very cold day is less than 1,090 feet per second. Explain why this is a true statement.

2. Why is it difficult to understand the speaker in certain auditoriums?

3. Explain the method involved in the carbon microphone for changing sound to electrical energy.

4. Name several advantages of crystal microphones.

5. What is the voltage output of a phono-pickup?

6. How many DB increase is needed in order to make sound appear twice as loud? You remember that an increase of tenfold is needed before the sound appears twice as loud.

7. An amplifier stage having a gain of 31 D.B., represents what power ratio? (Approximate.)

8. On what main factor does the amplification of an audio stage depend?

9. Does the audio transformer increase power or does it increase voltage? Explain the answer.

10. In your own words, define different *Classes* of tube operation.

11. What are some of the advantages of resistance coupled audio stages? What are the disadvantages?

12. In a resistance coupled stage, the increase in plate current will cause the *actual* voltage present at the plate to increase or decrease? How do you explain the results?

13. Make sketches of identical audio stages which obtain their bias by several different ways.

14. What is the capacitive reactance of a 20 mfd. cathode by-pass condenser to an audio frequency of 100 cycles?

15. If in the circuit of Question 14, a 400 ohm resistor is used, which path (the condenser or resistor) will offer less opposition to the audio current of 400 cycles?

16. Explain three different kinds of distortion which may be present in an audio amplifier.

17. How does a vacuum tube amplify?

18. Name several advantages of push-pull operation.

19. How can a change of phase be produced? Name the two methods described in the text.

20. What are the advantages of Class B amplifiers?

21. How does the dynamic loudspeaker work?

22. What is the turns-ratio between the primary and secondary of a transformer which must match the tube plate impedance of 4,500 ohms to a 5 ohm voice coil?

LESSON 12

Radio Frequency Voltage Amplifiers

NEED FOR R.F. AMPLIFIERS. The radio frequency energy received by the antenna is very weak. Since vacuum tubes used in a radio receiver, except for the power output stage, are voltage operated devices, we are interested primarily in increasing the voltage of the wanted station as received by the antenna system. We know that the amplification can take place at audio frequencies after the audio component has been removed from the R.F. wave. However, the audio section can only amplify the intensity of the signal, while the circuits used for radio frequency amplification not only amplify the incoming signals, but also select the desired signal from all the signals which excite the receiving antenna. Radio frequency amplifiers, in other words, *tune-in* the desired station and suppress the signals of the stations which are transmitting but are not wanted at the moment; besides amplifying the signals of the desired station.

INPUT CIRCUIT. The input circuit to a radio frequency amplifier tube consists of a radio frequency transformer. If the transformer serves the first R.F. stage, it has its primary coupled to the antenna circuit. The secondary is loosely coupled to the primary and is tuned with a section of a variable condenser. One terminal of the secondary is connected to the control grid of the tube used, while the other terminal is connected to the grid return.* Sometimes this ground end of the secondary is connected to the cathode through a by-pass condenser. While this condenser may block D.C., it presents almost no reactance to the R.F. voltage. Although the *transformer* action actually steps the voltage down (since the mutual inductance is small), the *Q* of the secondary is high and a voltage gain results. It is proper to think of the primary as a generator inducing minute voltages in each turn of the secondary and all these small voltages adding together. The current, as you can see, will circulate around the circuit which includes the tuning condenser, and we have the equivalent series circuit. The voltage drop across the condenser will be impressed on the grid of the R.F. tube. This voltage, present across the tuning condenser, will be exactly the same as developed across the inductance of the secondary circuit. You must recall that at resonance in a series circuit, the voltages across the condenser and coil are equal in value.

The frequency of the station wanted is *tuned-in* with the variable condenser. Energy of a frequency will develop the maximum voltage across each reactance of the series secondary circuit when that circuit is resonant to this frequency. At the same time, the stations operating on other frequencies will develop very small interfering voltages. To be absolutely correct, we must admit that the condenser really tunes both the primary and secondary coils to be resonant at a frequency which will give the best total result for the particular station wanted.

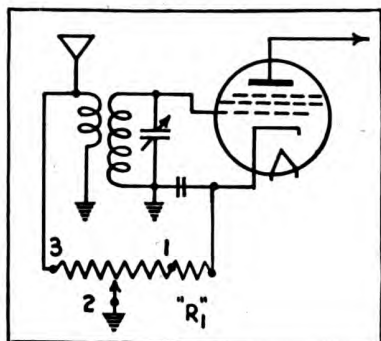
The tubes employed in radio frequency stages amplify all signals delivered to them, but the tuned circuits used in these stages select and increase the voltage of the wanted frequencies.

This is true for the resonant frequency and this is the frequency in which we are interested.

The L-C combination is made resonant to the wanted frequency by adjusting the value of C.

*Grid return is considered the remaining connection from the component part which has its other terminal connected to the control grid. In this case, it is one of the terminals of the secondary coil.

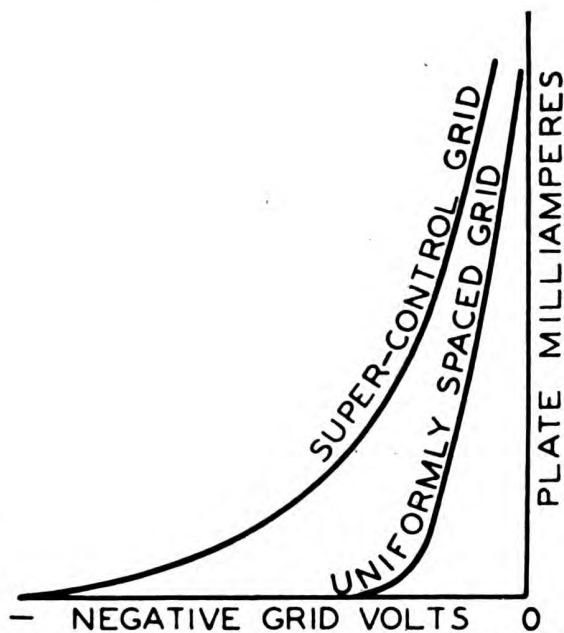
RADIO FREQUENCY AMPLIFIERS



Courtesy International Resistance Co.

Figure 181. A circuit of a R.F. amplifying stage showing the details of the volume control.

Compare the data on 6K7 and 6J7 tubes, as given in the characteristic chart. The 6K7 is a super-control tube, while 6J7 produces approximately equal changes in the plate current for equal changes in the grid voltage.



Courtesy RCA

Figure 182. In vacuum tubes with uniformly spaced grid wires, the grid-voltage plate-current curve is straight for operating conditions when the grid bias voltage is not too large. If the negative grid voltage becomes larger, as required in adjusting the volume for a local station, operation takes place over the curved portion. In the super-control grid tubes, any small section of the curve is relatively straight.

When a coil is used to couple the first R.F. stage to the antenna, it is called the antenna coil. When a similar type transformer is used to couple two R.F. stages, the coil is called the R.F. coil. Less impedance may be used for the primary of the R.F. coil and the coupling employed is further reduced in some coils. The primary is connected to the plate of the tube of the preceding stage and to the positive plate supply. The secondary is connected to the grid of the tube in the following R.F. stage and to the grid return.

TUBES USED FOR R.F. AMPLIFIERS. When only triodes were available, naturally they were used for R.F. amplifiers. However, because of capacity effects between the elements, triodes permitted only limited amplification and had to be operated in a special bridge circuit which permitted the grid to plate capacity to be neutralized out. Great progress was made possible with the invention of the tetrode. This later tube eliminated the need for neutralization since the grid to plate capacity was reduced and this reduction permitted much higher amplification per stage. The pentode type tubes are now used in the R.F. voltage amplifier stages and give even higher gain. The variable mu pentode amplifier tubes permit the control of gain by the method of increasing or decreasing the negative grid bias. Other type of tubes would cause cross modulation or other type of distortion.

Remembering that the inter-electrode capacity between the different elements should be small and that the amplification factor (or the transconductance, if you wish to consider it instead) must be high, please check the suitability of the following tube types for R.F. amplification purposes:

Triodes: 26, 27, 30,
Tetrodes: 24A, 35,
Pentodes: 6D6, 6U7, 12K7.

OUTPUT CIRCUIT. The tube used in a R.F. stage must be *loaded* with an impedance that is high to radio frequencies. A resistor of several megohms would not do because it will also cause a D.C. voltage drop when the plate current passes, and this drop will leave very little voltage at the plate of the tube. However, a parallel tuned circuit in the plate lead would offer very high impedance to R.F., while the low D.C. resistance of the coil would permit an easy passage for the D.C. plate supply current.

In practice, the plate is loaded with the primary of a R.F. transformer (R.F. or I.F. coil) and this coil winding has the proper value of capacity shunted through the action of mutual inductance of the secondary circuit. In adjusting the tuning condenser connected across the secondary of the R. F. coil, you are also tuning the primary to resonance.

A parallel tuned circuit has different values of impedance to various frequencies. The maximum impedance is present to the resonant frequency; i. e., the frequency to which the circuit is adjusted. All other frequencies *find* less impedance. The further away a frequency is from the resonant frequency, the less impedance the tuned circuit presents to this off-resonance frequency. The voltage developed across the load impedance and indirectly transferred to the control grid of the following stage, depends on the product of the impedance and the current, $E = I \times Z$. Since the impedance, Z , is greatest for the resonant frequency which is wanted, this frequency will produce the greatest voltage on the grid of the next tube. All other frequencies will produce much smaller voltages.

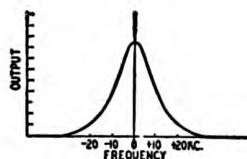


Figure 183. The output voltage of a circuit adjusted to one frequency, will vary as the frequency is changed.

Courtesy P. R. Mallory & Co.

At resonance, a parallel tuned circuit offers very high impedance.

For simplicity, we assumed that all frequencies present had the same value of current.

RESPONSE CHARACTERISTICS. The graph we have included on this page illustrates the voltage in the output of the stage at different frequencies away from the resonant frequency. The resonant frequency is marked 0, and frequencies above and below this value are considered. Points marked +10, +20, indicate frequencies greater by 10 and 20 kilocycles, while the points marked -10, and -20, indicate frequencies lower than the resonant frequency by 10 and 20 kilocycles. Notice how the output drops off as the frequencies (off the resonant signal frequency) move away from this resonant frequency. Twenty kilocycles away, very little voltage output is present.

As you will learn in the next chapter, a broadcasting station transmits audio frequencies up to about 5,000 cycles, and this causes the radio waves of the station to include frequencies that vary up to 5,000 cycles from the carrier frequency, at certain instants. A station transmitting at 950,000 cycles per second (950 KC.) may at times have frequencies of 950,000 cycles, plus and minus 5,000 cycles. The side-bands, as these new frequencies are called, will be in this case 955 KC. and 945 KC., a variation of +5 KC. and -5 KC. from the carrier frequency.

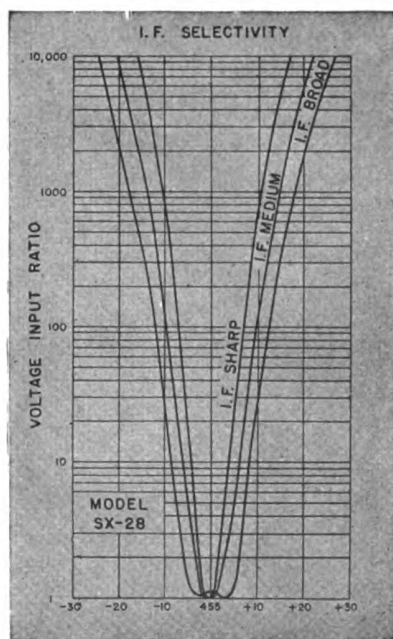
If the tuned circuits are adjusted to some new frequency, this new frequency, in turn, will produce the maximum voltage drop while all other frequencies (and including the one previously predominating) will produce much smaller values of voltage.

TYPES OF RESPONSE CURVES

A radio station does not transmit a single frequency. A band of frequencies are transmitted, in reality. The tuned circuits should be capable of passing this entire band, with but little variation in the amplification.

Various I.F. frequencies are used by different receiver manufacturers. Values of 175, 456, 465 KC. are quite often used.

The resistance is a function of the frequency when used at radio frequencies.



I.F. selectivity curves obtainable with the different adjustments incorporated in *Hallicrafters* SX-28 receiver. Base line is graduated in KC. off the I.F. frequency of 455 KC. Ordinate scale indicates loss ratio of voltage.

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A good R.F. amplifier stage will have a response that gives a curve which is flat across the top. This approximate flatness should extend to 5 KC. on each side of the resonant frequency being received. In this way, the carrier and the side-bands up to 5 KC. will be received with equal amplification giving a constant output. Frequencies beyond this point will represent interfering stations when this one particular adjustment is made. Therefore, the curve should be flat across the top for 5 KC. on each side of the resonant frequency, and then the curve should drop very steeply to the base line representing no output beyond these points. Such an ideal curve cannot be obtained in practice, and the curve illustrated represents good achievement.

INTERMEDIATE FREQUENCY AMPLIFICATION. In the superhetrodyne receiver, as explained in Lesson Fourteen, the frequency of any wanted station is changed to a fixed frequency usually about 450 KC. The original side-bands of the station being received become corresponding side-bands of this new intermediate frequency or I.F. The transformer, I.F. coil used to couple such stages, may be designed to give better results than the R.F. coil which is tuned to resonance for each station to be received. Let us consider the limitations of R.F. transformers, which are used to receive many frequencies, and see how the I.F., which is a single frequency transformer, eliminates these faults.

We have already learned what type of response curve is ideal for a broadcast type R.F. amplifier stage, and what type of response curve is obtainable in practice. You must also understand that the height of the curve, i. e. the voltage of the output, depends on the resistance of the circuit. The radio frequency resistance of a coil (because of the skin effect) changes for different frequencies and is greatest for high frequencies. This factor makes the amplification change for various frequencies of the broadcast band, which is 540 to about 1,750 KC.

The shape of the curve obtained depends on the Q of the coil. If the Q is large, the curve is narrow and has steep sides. If the Q is small, the selectivity curve spreads out and is almost flat over a large frequency variation. Since the value of Q is computed by multiplying the fixed quantity 6.28 by the inductance of the coil in henries by the frequency of the circuit, and dividing the result by the resistance which changes but little, the Q varies primarily with frequency. In the broadcast band, the value of Q may vary by a ratio of $2\frac{1}{2}$, from the lowest to the highest frequency of the band. This variation, of course, gives different degrees of response to different frequencies. If the R.F. coil is designed to give proper response at one frequency in the center of the band, the response may be too sharp at one end and too broad at the other end.

If the tuned circuit can be made to operate at a definite single frequency, it may be designed to give optimum results at this frequency. This is just what is done in the case of the I.F. transformer. High gain is obtained and the response curve indicates that the output is almost flat within the required band width of 5 KC. on each side of the I.F., and falls off sharply after these frequencies.

I.F. TRANSFORMERS. The intermediate frequency transformers used in commercial equipment have taken many forms, but most commonly these transformers consist of a primary and a separate secondary coils, each coil tuned with a semi-adjustable trimmer condenser. A few I.F. transformers have only the secondary tuned. In most cases the primary and secondary are identical coils, mounted

on a wood doll-rod. The assembly is placed inside a shield-can, and the one or two trimmers are mounted in the upper section of this can. Although the Q of the coils is fairly high, the mutual inductance is small (coefficient of coupling, k , is very small, i. e. coupling is loose) and the over-all voltage gain of the I.F. transformer is about one or two. The I.F. transformer is very selective and is especially useful for this reason. The required gain is easily obtained in the high-gain pentode tubes used in the I.F. stages.

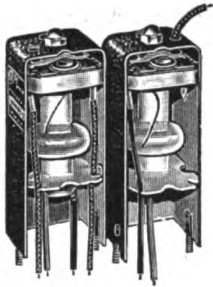
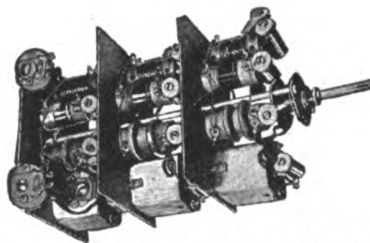


Figure 184. Inside views of an I.F. transformer. The output type I.F. transformer is usually connected to a diode detector and has four leads coming out of the bottom. The interstage or input type I.F. transformer has the grid lead at the top.

Courtesy Meissner Mfg. Co.

MULTI-BAND RECEPTION. The frequency covered by any L-C circuit depends on the value of inductance and capacity. In most practical circuits, the inductance is of a fixed value selected to give the required frequency coverage with the variable condenser employed. The inductance and the maximum capacity of the variable condenser, will tune to the lowest frequency; while this same inductance and the minimum capacity of the condenser will tune to the highest frequency covered by the L-C combination. It is practical to manufacture variable condensers which have a ratio of 9 to 1 between the maximum capacity and minimum capacity, with the stray capacities of the circuit included in these figures. This capacity ratio will give about 3 to 1 frequency ratio. For example, the broadcast band is about 3 to 1 ratio (540 KC. goes into 1,750 KC. a little over three times). What must be done to receive frequencies beyond this band?



Courtesy Meissner Mfg. Co.

Figure 185. The coils for multi-band reception may be mounted around the band-switch for convenience and to permit short connecting wires.

In order to receive frequencies outside of the broadcast band, usually higher frequencies, either the coil or the tuning condenser must be changed. It is not practical to change the variable condenser gang, and a change in the inductance is made instead. If only another band above the frequencies the broadcast band is to be covered, it is possible to tap only a part of the windings of the coil (secondary) used for the broadcast band. A lower inductance

I.F. AND MULTI-BAND COILS

How single frequency transformers (I.F. coils) can be utilized to receive a variety of stations operating at different frequencies, is explained in Lesson 14.

The adjustable condensers are at the top of the can. These condensers are adjusted for proper operation and then need not be altered.

Highest frequency is received when the rotor plates of a variable condenser are all the way out.

Multi-band reception is preferred since many interesting programs and foreign stations may be received on frequencies outside of the broadcast band.

MULTI-BAND COIL CONNECTIONS

In some all-wave sets, the trimmers of the variable condenser are used for one of the bands and separate trimmer condensers are provided for the coils used for the remaining bands.

then will be obtained. A switch may be used to make this change from total inductance to a part of the inductance. A multi-section switch completes this change in several coils (antenna, R.F., etc.) at the same time.

The better radio receivers, of course, are designed for the reception from several bands, and for best results separate coils are used for each band. A multi-contact switch does the required switching. The leads to the switch must be very short. In some sets, the unused coils are left unconnected, but in others the coils, not used when the switch is in any one position, are grounded or shorted to ground to eliminate dead-spots in the band being received. Each group of coils may be included in a single shield. One shield may have four antenna coils for four bands, while another shield may have four R.F. coils. Since the same variable condenser is used for all bands, the trimmers of the condenser gang cannot be used, and each individual coil employed has a separate trimmer to compensate for circuit differences.

The intermediate frequency transformers of a given frequency serve the multi-band receiver just as well, since on all bands the superheterodyne action changes the incoming frequency to the fixed I.F. The circuits used are similar to a regular, single-band receiver, but extra sets of coils are included.

1. Consider the entire stage.

REVIEW QUESTIONS AND PROBLEMS. 1. What two functions does a R.F. amplifier perform?

2. How do you explain that the usual R.F. input circuit appears to be a parallel circuit, but behaves as a series circuit?

3. What types of tubes are used in practice? Why were type 27 triodes used as R.F. amplifiers at one time?

3. Why do pentodes make better R.F. amplifiers than triodes?

4. How does the impedance of a parallel tuned circuit varies with frequency? Why is this useful for radio work?

6. The extreme frequencies are wanted for the answer.

5. Make a graph of an ideal response curve. Make a graph of a very poor response curve.

7. Is this response curve suitable for a high fidelity receiver?

6. A broadcast station operating on 670 KC. may be sending out what frequencies during some instants?

8. Can this change be made in a small midget receiver?

7. Sketch a response curve of a circuit having very high Q and very low resistance.

8. What simple change will be required in a R.F. amplifier circuit which has been designed for broadcast reception, to receive police band signals of about 1,900 KC.?

LESSON 13

Detection

WHAT HAPPENS AT THE RADIO STATION. In order to understand the need for detection in the radio receiver, we must consider what takes place at the transmitting station. Detail explanation about transmitter circuits will be given in a later chapter, but now we will learn the general function of the transmitting station. A special vacuum tube circuit produces the radio frequency which is assigned to the particular station. If the station is operating in the United States broadcast band, the frequency may be between 540 and 1,750 kilocycles. The radio frequency energy of this circuit is amplified by many additional stages. The last stage is coupled to the transmitting antenna which radiates electromagnetic waves into space. It is these waves that induce a corresponding radio frequency voltage in every receiving antenna.

The radio frequency waves induce an alternating voltage in the receiving antenna. Since the RMS value of this induced voltage does not vary, no information is transmitted from the station to the receiver. We can think of the radio frequency wave as a truck designed to carry loads, but arriving at the destination (receiver) without any load. The truck itself serves no purpose; it is the load (that is speech, music, telegraphy, or television) in which we are interested. It is obvious, therefore, that the radio frequency energy transmitted by the station must be *loaded* with "communication" we wish to transmit to the receiver.

In radio telegraphy, the radio frequency energy or the carrier frequency is interrupted in accordance with a code which is used to spell out words. Such transmitters are called CW (continuous wave) and are *keyed* by the operator. It is also possible to begin with sound, voice or music, amplify this sound with the equivalent of a public address amplifier system, and use the audio energy available to vary the intensity of the radio frequency wave transmitted by the station. Please observe that the *frequency* of the radio frequency wave is not altered, but the *amplitude* (height) of the wave is varied in accordance with the audio frequency variations.* When the carrier wave is so varied or *modulated*, the voltage induced by this station in the receiving antenna will also vary in accordance with the audio frequencies originating in the studio at the station. The information needed is carried by the radio wave, but the actual information is of an audio frequency.

WHAT HAPPENS IN THE RECEIVER. Among all other signals, the antenna of our receiver is having a voltage induced upon it corresponding to the frequency of the station we wish to receive. This radio frequency signal is varying in intensity (amplitude) in accordance with the audio variations of the sound being transmitted. The radio frequency of this varying amplitude is amplified by the R.F. and I.F. section of the receiver. The resulting voltage delivered to the detector stage, which is located before the audio section of the receiver, is similar to the varying voltage received by the receiving antenna but is much larger in value. The job now is

*Reference is made to the more commonly employed type of amplitude modulation. In frequency modulation (F.M.), the frequency is varied.

Here is an explanation of radio transmission.

The instantaneous value does vary at a radio frequency rate, but produces no effect as far as the response from the speaker of the receiver is concerned. The *average* value over several cycles must vary to produce an audio response in the speaker.

Actually, the power transmitted is increased.

The voltage on the receiving antenna will vary with the audio energy.

Not only is this wanted voltage amplified, but all other voltages (of stations operating on other frequencies) are reduced and suppressed in the same process.

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CHANGES IN R.F. WAVES

More commonly, demodulation is simply called detection.

You are really visualizing the appearance of the voltage variations over a period of time. The vertical scale is used to represent the value of the voltage, while the horizontal scale represents time with the later instants of time to the right.

The R.F. carrier waves are sine waves.

to remove the audio variations which were placed on the radio frequency carrier at the transmitting station. As you can see, in the audio section of the receiver we no longer need the R.F. carrier. Thinking of the carrier once again as a truck and of the audio frequencies as the load, we are now at the place where the load must be removed. Since we have plenty of our imaginary trucks, once the loads are removed the trucks can be junked. The detector performs this function of removing the audio signals. Since the process of placing the audio on the carrier is called modulation, the removal of the audio may be called demodulation.

APPEARANCE OF THE RADIO-WAVE VOLTAGE. It is possible to visualize the appearance of the voltage produced by the radio wave from instant to instant. A transmitter, when no modulation is present, impresses pulses on a parallel inductance-capacity circuit tuned to resonance, and sine waves of the natural frequency of this circuit are produced. There are as many such waves per second as the numerical value of the frequency in cycles per second. Audio modulation increases or decreases the intensity of the pulses delivered to the L-C circuit, and the resulting wave form will be increasing or decreasing in accordance with these audio variations. Since a larger voltage of the pulse, shocking the circuit, will produce a sine wave which will be larger, both the lower and upper sections of the train of sine waves will increase. As the illustration shows, the constant maximum amplitude R.F. carrier is increased or decreased in voltage (height, amplitude, intensity) in accordance with the audio signal. The envelope of the modulated R.F. wave

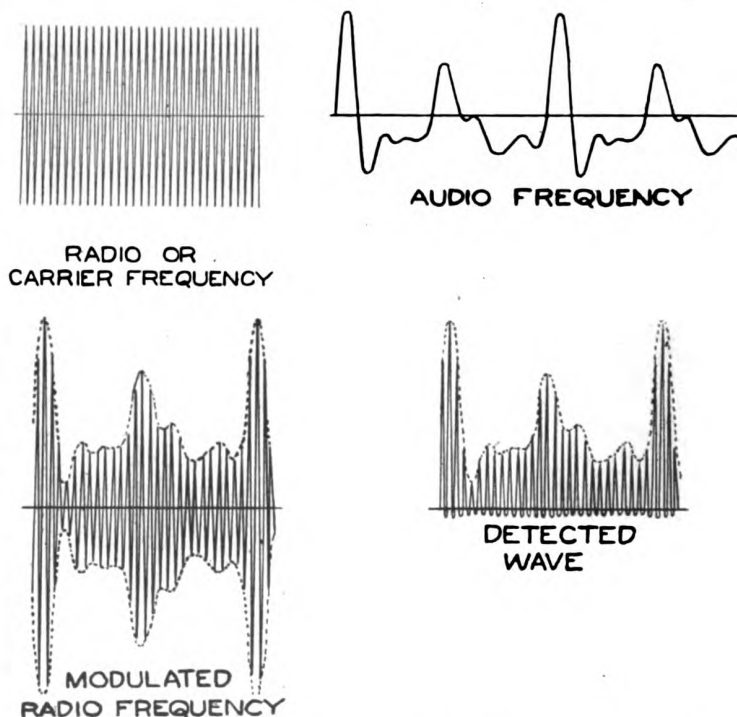


Figure 186. The radio frequency carrier is a succession of sine waves at a definite frequency and of equal maximum amplitude. The audio frequency, produced by a musical instrument or voice, has a changing frequency between about 25 and 5,000 cycles, as used in radio work. The audio frequency varies the amplitude of the carrier, as illustrated. The detected wave contains only the upper portion of the received, modulated radio frequency.

forms a pattern above and below the wave train, and this pattern is the representation of the audio frequency which is modulating the signal. Notice that the lower envelope is this audio frequency also, but in reverse.

With any varying signal, the average voltage over several cycles will be zero. This is so because the voltage of the wave increases and decreases by the same amount over the adjacent R.F. cycles. The detector must eliminate (or greatly reduce) the lower portion of the R.F. voltage curve. Further, the remaining upper portion of the R.F. voltage train (as modulated by the audio frequency) must be smoothed out so that an average audio signal will remain. Several different type of detectors are used in commercial practice.

CRYSTAL DETECTOR. Although in modern radio sets, vacuum tubes are used as the detectors, in the early days of radio and for micro-wave work at present, crystal detectors found a ready application. A crystal detector consists of a mounted crystal of some special material such as galena, iron pyrites, or carborundum, and uses a thin copper wire to make the needed contact. When an alternating current of any frequency is applied to the crystal, it flows in one direction only. When the voltage reverses its polarity, the crystal presents a very high resistance. Since the upper portion of the wave train of the R.F. represents polarity in one direction, while the lower half represents polarity in the opposite direction, detection will take place.

A small capacity condenser (about .0003 mfd.) is placed across the crystal output circuit. This condenser must not be so large as to by-pass audio signals, but it must be large enough to smooth out the gaps between the *half-sine-waves* and produce an average value of voltage which will correspond to the audio voltage originally used to modulate the wave at the transmitter.

DIODE DETECTOR. A diode section of a vacuum tube can be used in place of the crystal detector. A diode, of course, conducts only when the plate is made positive. This fact will permit detection to take place. The voltage is developed across the load resistor, and then is impressed on the audio amplifier. The small condenser shunts this load resistor and smooths out R.F. variations. In prac-

SIMPLE RADIO DETECTORS

To be absolutely correct, we must realize that *either* the lower or upper portions of the R.F. voltage wave must be eliminated.

A crystal used for detection passes electric current in one direction only — just as any diode rectifier.

A condenser of this type is often used with other types of detectors for the same purpose.

Examine the diode detector circuit under B, Figure 188, on the next page. The resistor in the cathode is the load resistor, while the by-pass condenser, we mentioned, is across this load.

A practical power detector, of course, does not use batteries. The required *high* bias voltage is obtained with a 10,000 to 50,000 ohm cathode resistor (see circuit C, Figure 188).

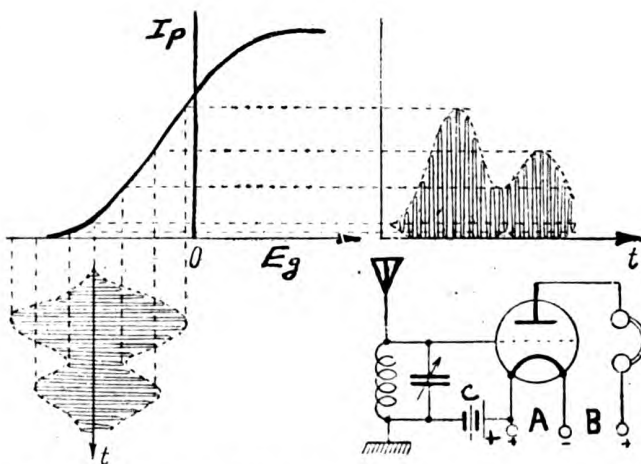


Figure 187. A biased or power detector is operated at that point of its characteristic curve where a much greater plate current change occurs on positive peaks than on the negative peaks.

OTHER TYPES OF DETECTORS

Illustration below, circuit C.

To understand the curves placed on the right of the circuits, you must realize that they show the relationships between grid voltage and plate current. The instantaneous grid voltage is plotted on the horizontal scale, while the plate current is indicated on the vertical scale. To fix the idea, consider the bottom curve for a power detector. With no signal, the grid voltage will be at the point crossed by the dotted line of the I scale. Very small current will be present. If the signal is positive at the instant, shifting the instantaneous grid voltage to the right (positive direction), the plate current, I , will increase an amount indicated by the dotted lines. A corresponding instantaneous negative signal voltage will shift the grid voltage to the left (negative direction). However, in this latter case, the plate current decrease will be smaller (much smaller) than the rise with a corresponding positive signal voltage.

tice, the load resistor may be 500,000 ohms, while the condenser may be .0001 mfd. mica type.

PLATE DETECTOR. It is possible to adjust the bias of a triode tube, so that the plate current is near cut-off. The grid bias required may be obtained from an outside circuit or the tube may use a cathode-resistor circuit. In the usual practical circuit, the cathode resistor is between 10,000 and 50,000 ohms. As you can see from the illustration, the positive portions of the R.F. will be amplified a great deal, while the negative portions will reduce the minute minimum (no signal) current very little. The plate current passing through the tube, therefore, will depend primarily on the positive portion of the R.F. and will reproduce this wave-shape greatly amplified.

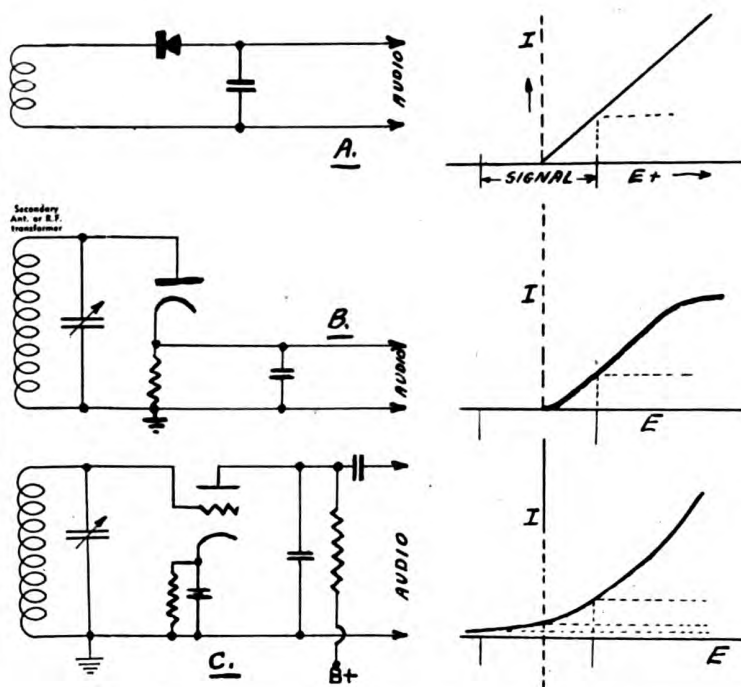


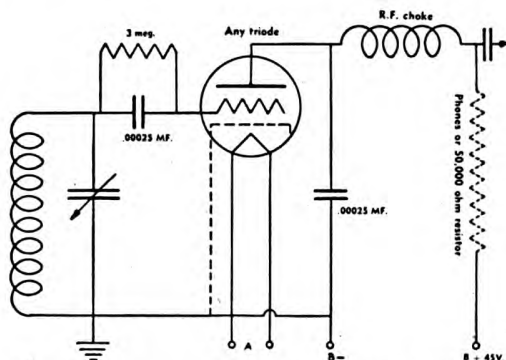
Figure 188. A crystal detector circuit is shown in (A). This detector is essentially linear to the signal in one direction and has infinite resistance to the signal in the opposite direction. In illustration (B) a diode detector is shown. The principle of operation is similar. A power detector, using a self biasing resistor, is shown schematically in (C).

The result is similar to what we have obtained from other type detectors, but here we not only produced detection but have amplified the signal at the same time. This type of detector employs a process called *plate detection*. Plate detection is especially useful for handling large signals and may be used to drive the final power output audio tube directly.

GRID LEAK DETECTOR. This type of detector has a longer history behind it and is more sensitive than the plate circuit detector. The grid leak detector has limited power handling ability and is seldom used in modern radio receivers.

An examination of the circuit will reveal that the grid does not have any negative bias from any outside circuit. However, even at zero or slightly negative bias, the grid will attract some electrons

and a very minute current will pass through the grid circuit. The grid leak resistance will produce a voltage drop because of this current. The polarity of this voltage drop is such that the grid will be at the negative side, while the cathode will be at the positive side of the grid leak.



Courtesy Allied Radio Corp.

Figure 189. A grid leak detector is especially useful in circuits requiring considerable sensitivity. It is not used in modern radio sets.

COMPARISON OF DETECTORS

You should be able to make a schematic diagram of a grid leak detector circuit.

The R.F. signal reaches the grid through the grid condenser. The value of this condenser must be large enough to pass R.F. without much opposition, but if it is too large the corresponding audio voltages built up across the grid leak will be by-passed. The voltage on the grid at any instant will depend on the incoming signal. The incoming signal will be controlling the voltage of the grid and, thereby, the current in the grid circuit. But this current will vary the grid bias; it is this current that produces the voltage drop across the grid leak resistor.

We see that the voltage on the grid will depend on the signal. We must also realize that the grid-voltage-grid-current relationship is such that a negative signal will alter the value of the voltage many times more than a corresponding positive signal.

Since the plate current of this triode vacuum tube depends on the grid voltage, it will vary with the changes in the grid signal voltage. A negative portion of the R.F. signal reaching the grid will make the grid more negative, in addition to the negative bias, with a corresponding change in plate current. The positive portion will produce a much smaller change in the plate current, and detection will be obtained.

COMPARISON OF DETECTION METHODS. The crystal, diode, and grid leak detectors draw current from the tuned circuit and, thereby, lower both the selectivity and gain of the tuned circuit. A properly designed diode detector gives little distortion and is superior in this respect to the other types of vacuum tube detectors. Grid leak detection was formerly used extensively for detection of weak signals, but the development of improved radio frequency amplifiers has made this detector almost obsolete except for simple, experimental circuits.

REGENERATION. In radios of the 1923 period and in present day short-wave receivers, if the economy of tubes is important, a *regenerative* detector is employed. In this type of detector, a portion of the amplified energy from the plate of the detector is fed back to the grid circuit. This action will further increase the voltage of the signal in the plate circuit, and even greater amount will be returned

The operation of a grid leak detector circuit is difficult to understand and you may have to read this explanation several times to grasp the ideas.

If the circuit across L-C draws current, it has relatively low resistance. This resistance shunts the coil and lowers the Q.

REGENERATIVE DETECTOR

The principle of regeneration is similar to audio feedback described on pages 157-158.

See the figure below.

Regeneration may involve more than a single stage. However, such circuits are more difficult to control.

If you can obtain the needed parts, you may be interested in constructing this receiver. Remarkable long distance reception is possible with such a simple radio on short-wave. If you wish, you may use type 30 tubes instead. In such case, the screen grid connection (SG) of the 1N5-G is not used, and 2 volt *A* battery will be needed.

to the grid circuit. The feed-back must be of the correct phase relationship so that the grid will receive the returned energy in phase to re-enforce the original signal. The signals may be greatly amplified in this manner, but care must be exercised not to over do this process of returning the amplified signal. If the adjustment is made so that too much energy is returned, the tube will begin to oscillate and nothing but a whistle will be heard by the operator.

The schematic diagram of the two tube receiver, described in the next section, will help us understand this action. You can understand that the 1H5-G tube is used as a grid leak detector. The plate terminal of this detector tube has the signal corresponding to the upper portion of the R.F. train. The smoothing condenser of .001 mfd. capacity and the RFC (choke) have not been reached as yet. There is, therefore, at this point in the circuit, radio frequency energy. In order to reach the smoothing network (the condenser and choke) and pass on to the resistance coupled audio stage, the signal from the plate may go through a portion of the 50,000 ohm variable resistor (potentiometer) or may pass through the extra tickler winding placed adjacent to the antenna coil. If the potentiometer is adjusted to have a very low value of resistance, then the major portion of the energy will pass through this unit and very little will go through the coil. Under such conditions, the tickler coil will receive very little energy for the feed-back, and almost no regeneration (feed-back) will take place. However, if the potentiometer is adjusted so that almost the entire 50,000 ohms resistance is in the circuit, the coil will offer an easier path, and a great deal of regeneration will take place. The potentiometer may be adjusted to give the required amount of regeneration.

In some receivers, the control of regeneration is accomplished by varying the degree of coupling between the tickler and the antenna coils. The tickler may be rotated in reference to the antenna coil, or the two coils may be separated a greater distance to alter the amount of energy transferred between the circuits.

A SIMPLE RECEIVER. The most basic receiver may consist of nothing more than a tuned circuit to select the frequency of the wanted station and any detector to separate the audio from the carrier frequency. Years ago, crystal sets used a simple tuning

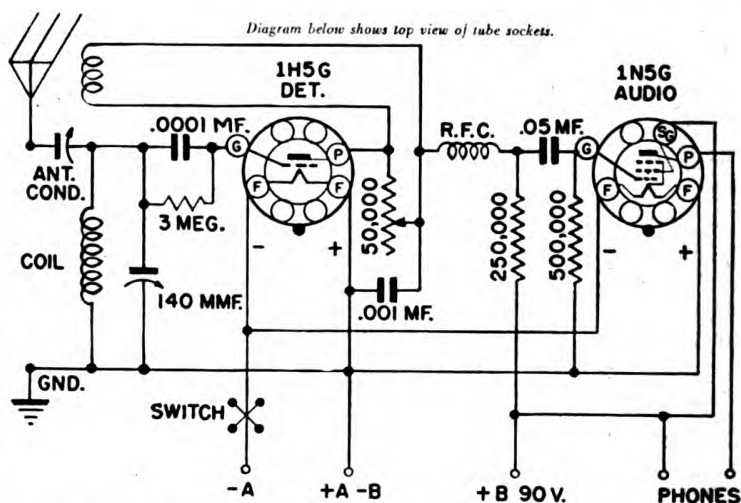


Figure 190. Circuit diagram of a two tube short-wave radio receiver consisting of a regenerative detector and a resistance-coupled audio stage.

arrangement and a crystal detector. Of course, all radios also require headphones or a loudspeaker to change the audio electrical energy to sound.

A more advanced two tube receiver is illustrated in picture form and by means of a schematic diagram. This is an interesting practical radio,* capable of receiving stations from great distances, and designed to cover wave-lengths from 9.5 to 550 meters with the aid of plug-in coils. Since the frequency of any radio station is related to its wave-length, you should know how to change one to the other.

$$\text{Frequency in kilocycles} = \frac{300,000}{\text{Wave-length in meters}}$$

$$\text{Wave-length in meters} = \frac{300,000}{\text{Frequency in kilocycles}}$$

First let us examine the circuit. Two low-drain battery tubes are used. We already described the regenerative detector. The antenna is coupled to the grid coil through a small antenna condenser which matches the antenna to the circuit. The tuning is accomplished with the 140 mmfd. variable condenser. Six plug-in coils are used to cover the frequencies from 545 KC. to 31,600 KC. (or 31.6 MC.). The audio stage uses a resistance coupled pentode. The headphones serve as the load for the plate circuit of this tube. Notice that the switch for turning off the unit is placed in the A — lead. This switch will break the circuit to the filaments of the two tubes. But if the tubes are not heated, they will not conduct any plate current. Therefore, although the B battery remains connected, it will not supply any current when the A battery circuit is broken with the switch.

REVIEW QUESTIONS AND PROBLEMS. 1. Explain how a music program is transmitted "through the air"?

2. Sketch a radio wave train which is modulated with an audio frequency.

3. What property of galena crystal permits it to be used as a detector?

4. Find a type of vacuum tube which could be used as a diode detector. Use the characteristic charts.

5. Can the cathode resistor of a plate detector be omitted? Explain your answer, showing the needed circuit in schematic form.

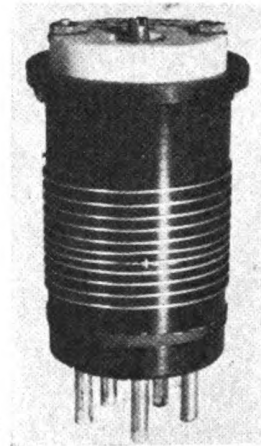
6. What will happen if the grid leak of a detector is made too large? Analyze the effects by going over the operation of the circuit.

7. What special advantages are there to a plate detector?

8. Explain what action will take place if the regeneration tickler coil is connected in reverse.

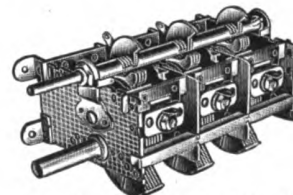
*Circuit diagram reproduced from the "Radio Builder's Handbook" published by Allied Radio Corp.

FREQUENCY TO WAVE-LENGTH



Courtesy Meissner Mfg. Co.

Figure 191. A short-wave plug-in coil with adjustable trimmer condenser. This coil is wound on a four-prong form, but five and six prong forms are used quite often.



Courtesy Meissner Mfg. Co.

Figure 192. By placing low capacity condensers in parallel with the larger capacity gangs, finer adjustment can be obtained.

4. Can you find a tube that could be used as a diode detector and also includes a high gain triode section for audio amplification?

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